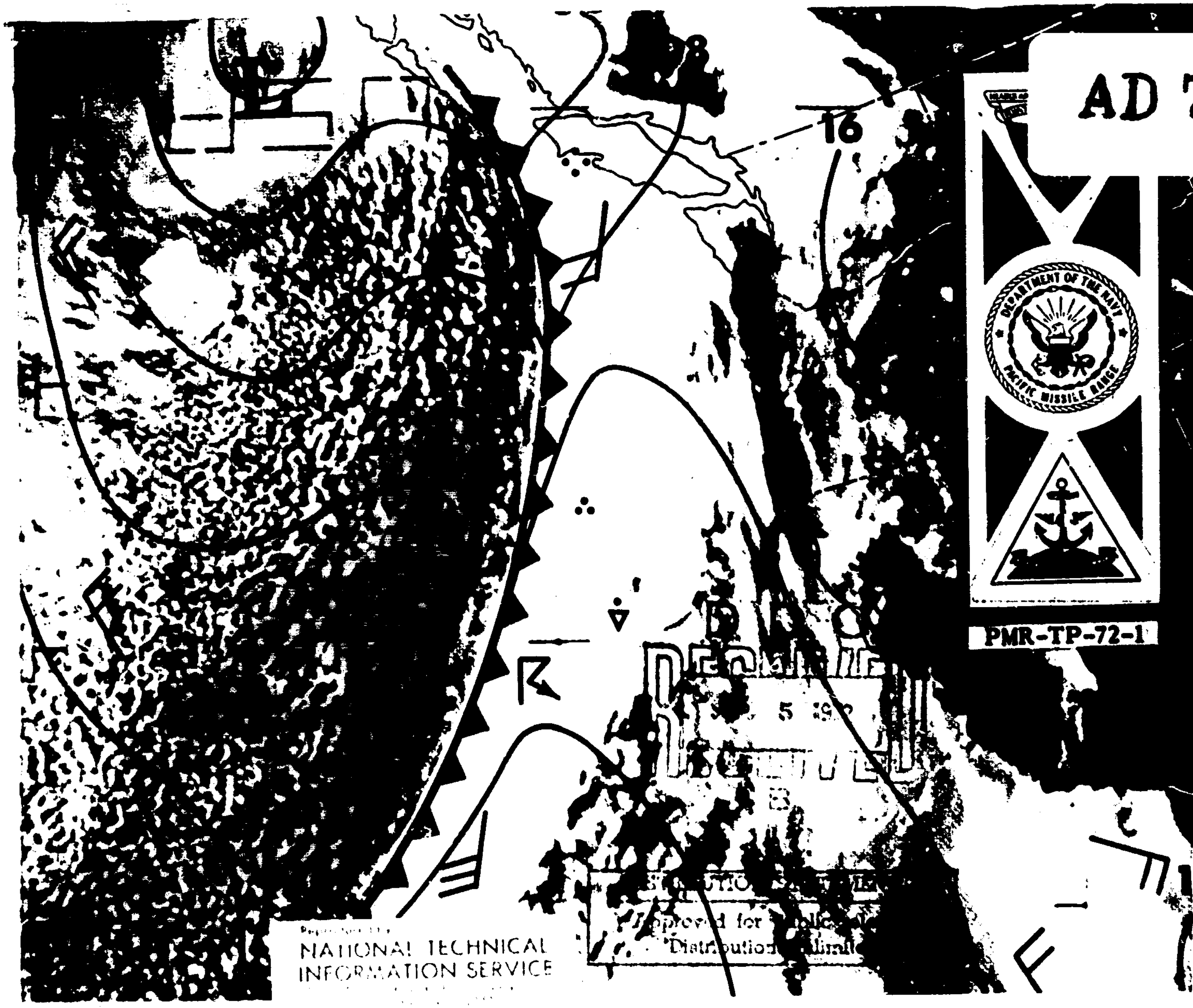

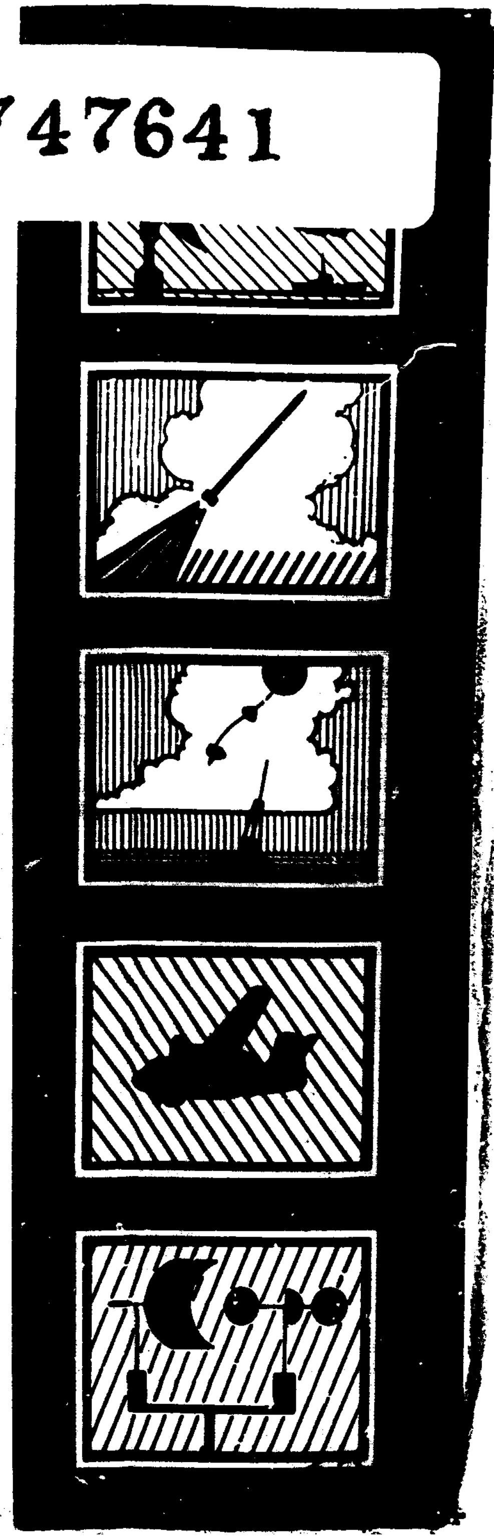

POINT MUGU FORECASTERS HANDBOOK

PACIFIC MISSILE RANGE, POINT MUGU, CALIFORNIA 93042
BY JAY ROSENTHAL, GEOPHYSICS DIVISION, 1 APRIL 1972

PACIFIC MISSILE RANGE

POINT MUGU, CALIFORNIA

H. S. MOORE, RADM USN
Commander

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Mr. D. A. Lea, Head, Atmospheric Sciences Branch, CDR R. C. Sherar, Head, Geophysics Division, CAPT L. H. Sette, Head, Range Operations Department, have reviewed this report for publication.

Approved by
W. L. MILLER
Technical Director

Technical Publication PMR-TP-72-1

Published by . . . . Editorial Branch
Technical Publications Division
Photo/Graphics Department
Security classification . . . . UNCLASSIFIED
First printing . . . . 315 copies

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

1. ORIGINATING ACTIVITY (Corporate author) Pacific Missile Range Point Mugu, California 93042	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP --

3. REPORT TITLE

POINT MUGU FORECASTERS HANDBOOK

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Jay Rosenthal

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1 April 1972	416	98

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) PMR-TP-72-1 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release, distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Pacific Missile Range

13. ABSTRACT

Three dominant weather patterns, or regimes, occur at Point Mugu and the local area throughout the year.

The stratus regime is the most striking, persistent, and important, from the viewpoint of range operations. It occurs throughout most of the spring and summer, but less frequently in the fall and winter. During this regime, low clouds and fog frequently cause poor visibilities and low ceilings in the morning, but during the afternoon hours conditions improve. Most of the fluctuations are caused by various subtle mesoscale influences such as local topography, sea/land breeze circulations, inversion height, and local sea surface temperatures. Large-scale synoptic changes are very weak and infrequent during the middle of the stratus season and are generally masked by larger diurnal fluctuations of cloud cover, winds, and temperatures.

The Santa Ana regime is the second most important weather pattern. Santa Ana conditions occur during the fall, winter, and spring months and rarely last more than a few days. Strong, dry northeasterly winds blow from the desert regions to the coastal area, and generally clear skies, excellent visibilities, and frequently above-normal temperatures result. As a rule, Santa Ana conditions are usually accompanied by excellent operational weather, however, when Santa Ana winds are exceptionally strong, visibilities may be restricted by blowing dust, and turbulence may become severe enough to pose a hazard to aviation.

The third dominant weather pattern, transient synoptic features, includes all the rain-producing storms and fronts and other causes of generally unfavorable weather. Rains are generally restricted to the fall through spring months and are usually followed by periods of fair weather, which can also be called transient because of their limited duration. Rainfall at Point Mugu usually lasts less than a day but, under certain rare circumstances, may continue nearly undiminished for a period of up to 4 days.

SUMMARY

Three dominant weather patterns, or regimes, occur at Point Mugu and the local area throughout the year.

The stratus regime is the most striking, persistent, and important, from the viewpoint of range operations. It occurs throughout most of the spring and summer, but less frequently in the fall and winter. During this regime, low clouds and fog frequently cause poor visibilities and low ceilings in the morning, but during the afternoon hours conditions improve. Most of the fluctuations are caused by various subtle mesoscale influences such as local topography, sea/land breeze circulations, inversion height, and local sea surface temperatures. Large-scale synoptic changes are very weak and infrequent during the middle of the stratus season and are generally masked by larger diurnal fluctuations of cloud cover, winds, and temperatures.

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CHAPTER 1

INTRODUCTION

Purpose and Content

The PMR (Pacific Missile Range) weather forecasters handbook (reference 1) is designed for use as a reference by forecasters and new personnel in the PMR Geophysics Division at Point Mugu. It contains descriptions and forecasting rules of the various processes at work in our atmosphere which directly affect local weather and which routinely concern PMR meteorologists during preparation of forecasts.

Many of the forecasting procedures for dealing with such Point Mugu phenomena as stratus, fog, Santa Anas, and rain are tentative but are, nevertheless, based on up-to-date meteorological reasoning or climatology. The handbook is simple enough to provide the forecaster with sound meteorological background to gain insight into particular forecast problems.

The handbook is not designed as a textbook to be read from cover to cover at one sitting but, rather, the intent is that pertinent sections be referred to as the need arises. Each subsection is self-contained

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and includes a list of forecast rules and aids. A certain amount of repetition was unavoidable. An index is provided to facilitate the location of desired descriptions.

Satellite pictures are also provided when available and when appropriate to the understanding of any subject. Geographical outlines of coastlines and individual western states have been superimposed on most satellite pictures to aid in photo interpretation and identification. Due to foreshortening at the edges of the satellite pictures and to difficulties encountered in photographic reproduction and printing, the geographical outlines do not perfectly conform to the true geographical or photographed features and in general represent nly a "best fit".

This introductory chapter includes topography of Point Mugu and San Nicolas Island, descriptions of meteorological instrumentation, and problems unique to local forecasting. More detail is provided in subsequent chapters.

It is intended that with proper understanding and application of the material in this handbook, the forecaster--particularly the forecaster new to the area--will increase the reliability and accuracy of his forecasts. Emphasis is on the dominant weather regimes in the local area. The determination of those weather conditions, a vital step in preparing any forecast, is aided by the wealth of data available to the PMR forecaster from all parts of the world. In addition, new

forecasting methods and local meteorological studies are provided by the Atmospheric Sciences Branch of the Geophysics Division. These incorporate parameters from the large-scale horizontal flow as well as from local land-produced anomalies on the sub-synoptic or mesoscale. As more information from these sources becomes available, it will be incorporated into future revisions of this handbook.

PMR Weather Center

The Geophysics Division provides services in the fields of meteorology, oceanography, aeronomy, and geodesy to all range users: Navy, Army, Air Force, National Aeronautics and Space Administration, Atomic Energy Commission, and directorates and subordinate commands of the PMR. Because the requirements of one user are not necessarily the same as that of another, the Division must tailor its weather forecasts to a variety of uses.

The weather services provided by the PMR Weather Center (figure 1-1) are comparable to those of an augmented Fleet Weather Central or Facility. The Weather Center operates a primary Navy APT (automatic picture transmission) weather satellite receiving station, uses data obtained from meteorological rockets that are launched daily to a height of 60 km (kilometers) and from rawinsondes which provide detailed data to about 32 km, and receives numerical weather analyses and forecasts from NMC (National Meteorological Center) and the Navy's FNWC (Fleet Numerical Weather Central). The Weather Center receives meteorological information from the entire Northern Hemisphere, ships at sea, Pacific islands, and Japan (upper-air data). It is capable of furnishing support for both local and extended operations throughout PMR on a 24-hour per day, 7-day per week basis. Meteorological data gathered by the Weather Center and subordinate units are relayed promptly to national and international weather services to contribute to improved world-wide forecasting.

Topography of Point Mugu and San Nicolas Island

Point Mugu (latitude 34°07' N, longitude 119°07' W) is located at the southern tip of the Oxnard coastal plain approximately 5 nmi (nautical miles) southeast of Oxnard, 4 nmi east of Port Hueneme, and 9 nmi southeast of the mouth of the Santa Clara River (figures 1-2 and 1-3). The field elevation is 12 feet above MSL (mean sea level), and the terrain rises gradually to the northeast and north. The Santa Monica mountains, an east-west range with peak heights of about 3,000 feet, lie immediately to the east. One of the peaks that markedly affect local weather is Laguna Peak, 1,450 feet high, that bears 104° (true north) and is only 3 nmi from the intersection of Naval Air Station runways 03-21 and 09-27 (figure 1-4). Approximately 15 nmi to the north, the Oxnard Plain ends and the first slopes of a region of higher terrain comprising the Topa Topa and Santa Ynez mountains begin. Approximately 25 nmi to the north, this higher

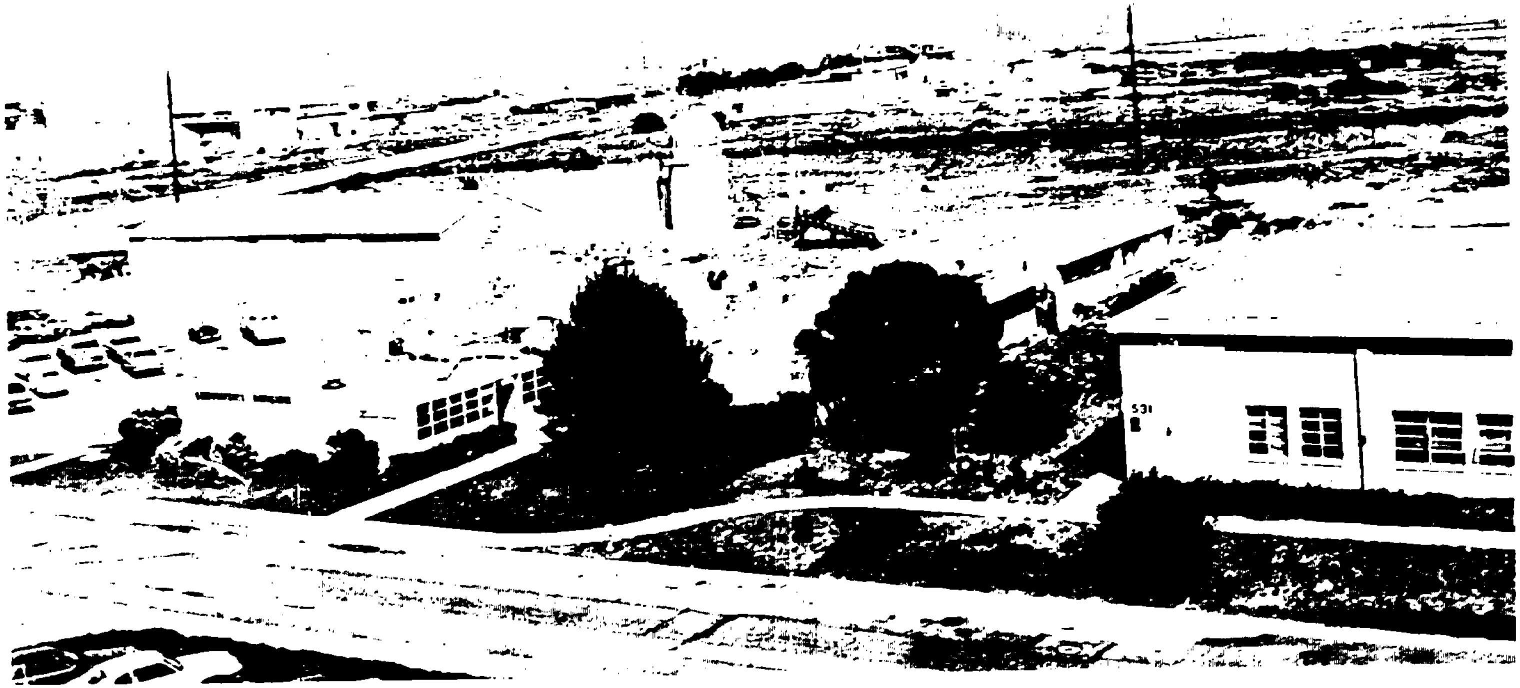

Figure 1-1. Main Offices of PMR Geophysics Division. Laguna Peak is on skyline; Mugu Rock is to far right

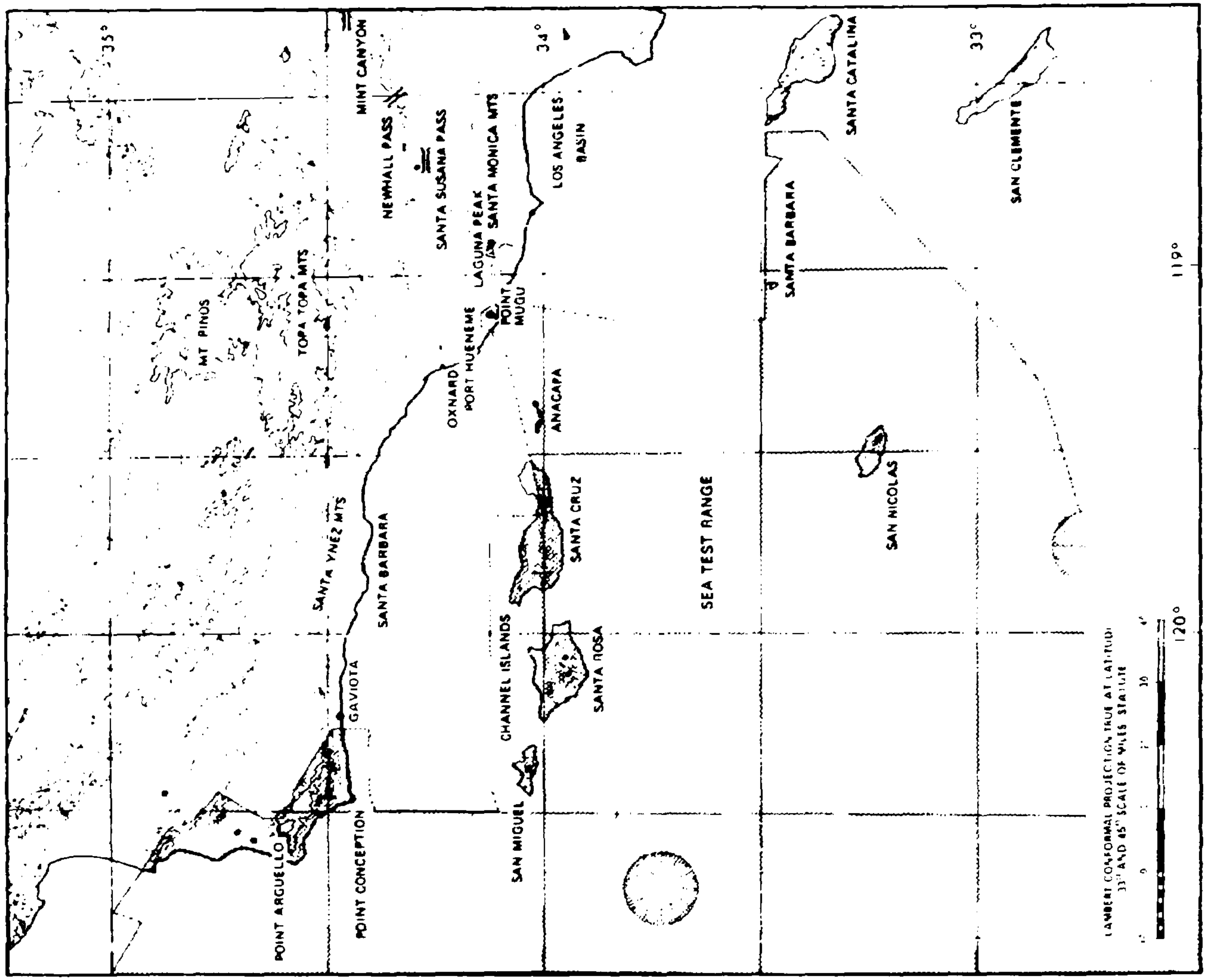

Figure 1-2. Point Mugu and Sea Test Range Areas.

terrain, averaging 6,000 feet in elevation, forms a nearly unbroken mountainous chain oriented east-west, and extending 85 miles westward along the coast to Point Arguello. Highest peaks are about 8,000 feet. It is this range of mountains that appears to form an effective barrier to storms and movements of air from the north and, at the same time, cause numerous downwind eddies which profoundly affect local weather.

Several canyons and passes, including such features as the Santa Clara River Valley, the Santa Susana-Simi Valley, and the Newhall Pass-Mint Canyon lie to the north and northeast of the Oxnard Plain and are oriented in a general east-west direction. These passes and canyons act as funnels for almost all the air originating in the higher desert and Great Basin* region which finds its way to Point Mugu.

To the northeast, counterclockwise through southeast, lies an expanse of ocean, open except for the following islands:

Island	Maximum Elevation (Feet)	Bearing From NTD** (Degrees True)	Distance From NTD (Nautical Miles)
San Miguel	861	264	63
Santa Cruz	2,471	263	35
Santa Rosa	1,589	258	50
Anacapa	930	246	17

Island	Maximum Elevation (Feet)	Bearing From NTD** (Degrees True)	Distance From NTD (Nautical Miles)
San Nicolas	907	200	56
Santa Barbara	565	176	38
San Clemente	1,942	156	85
Santa Catalina	2,125	143	61

The countryside surrounding Point Mugu is principally agricultural which causes two relatively minor visibility restrictions: dust and smoke. Dust is raised when Santa Ana winds blow over freshly plowed, dry fields, and smoke is produced during occasional periods of cold weather in winter when ranchers burn oil (or smudge) in an effort to prevent crops from freezing. Most of the non-natural visibility restriction experienced locally, however, comes from automobile and industrial pollution within the Oxnard Plain and from nearby Los Angeles Basin area.

The topography of San Nicolas Island can be briefly described as rugged. The official island

*The Great Basin is that area between the Sierra Nevada-Cascades and the Rockies that encompasses southeastern Oregon, southern Idaho, western Utah, and all of Nevada.

**NTD is Point Mugu

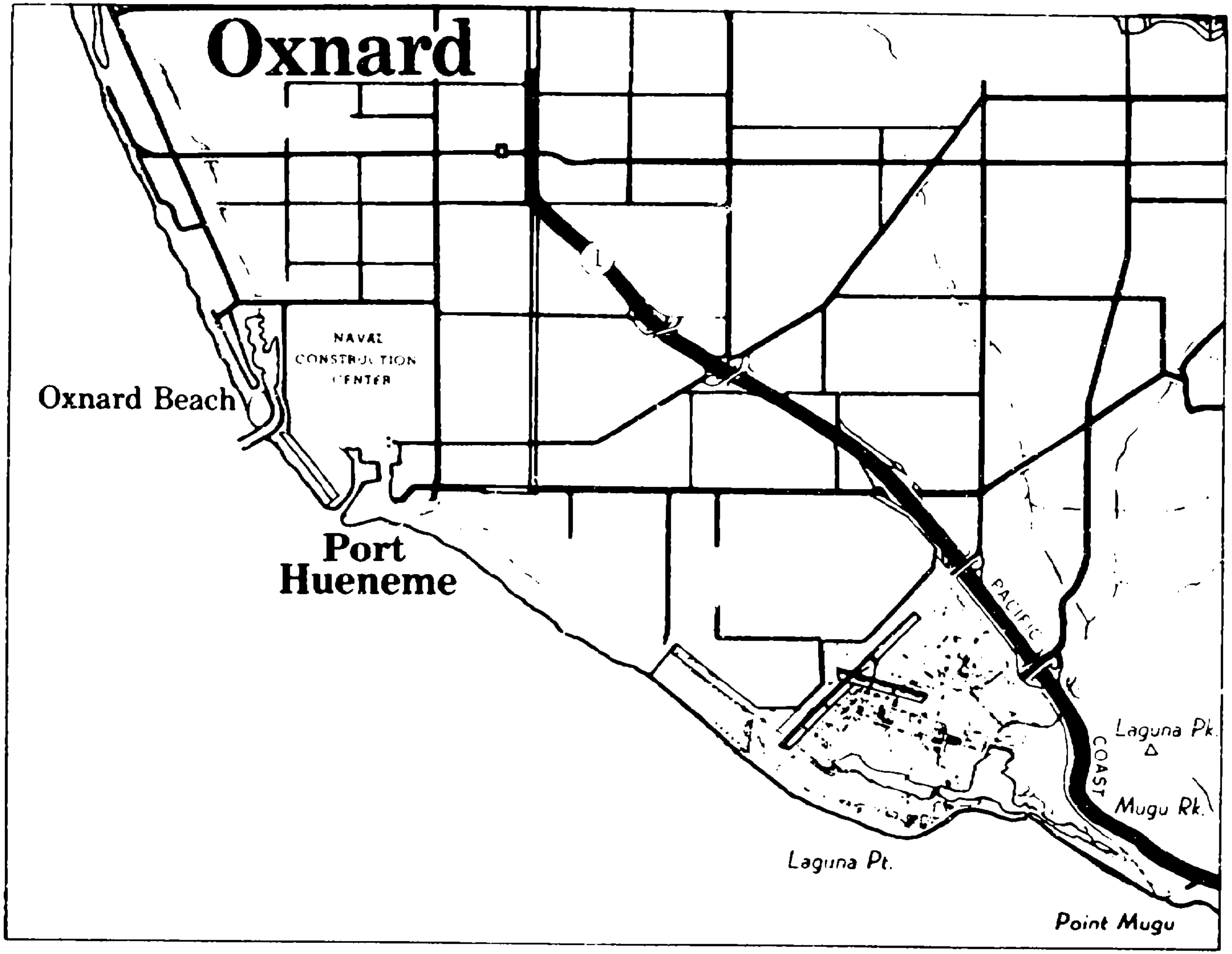

Figure 1-3(a) Point Mugu, Port Hueneme, and Oxnard Areas.

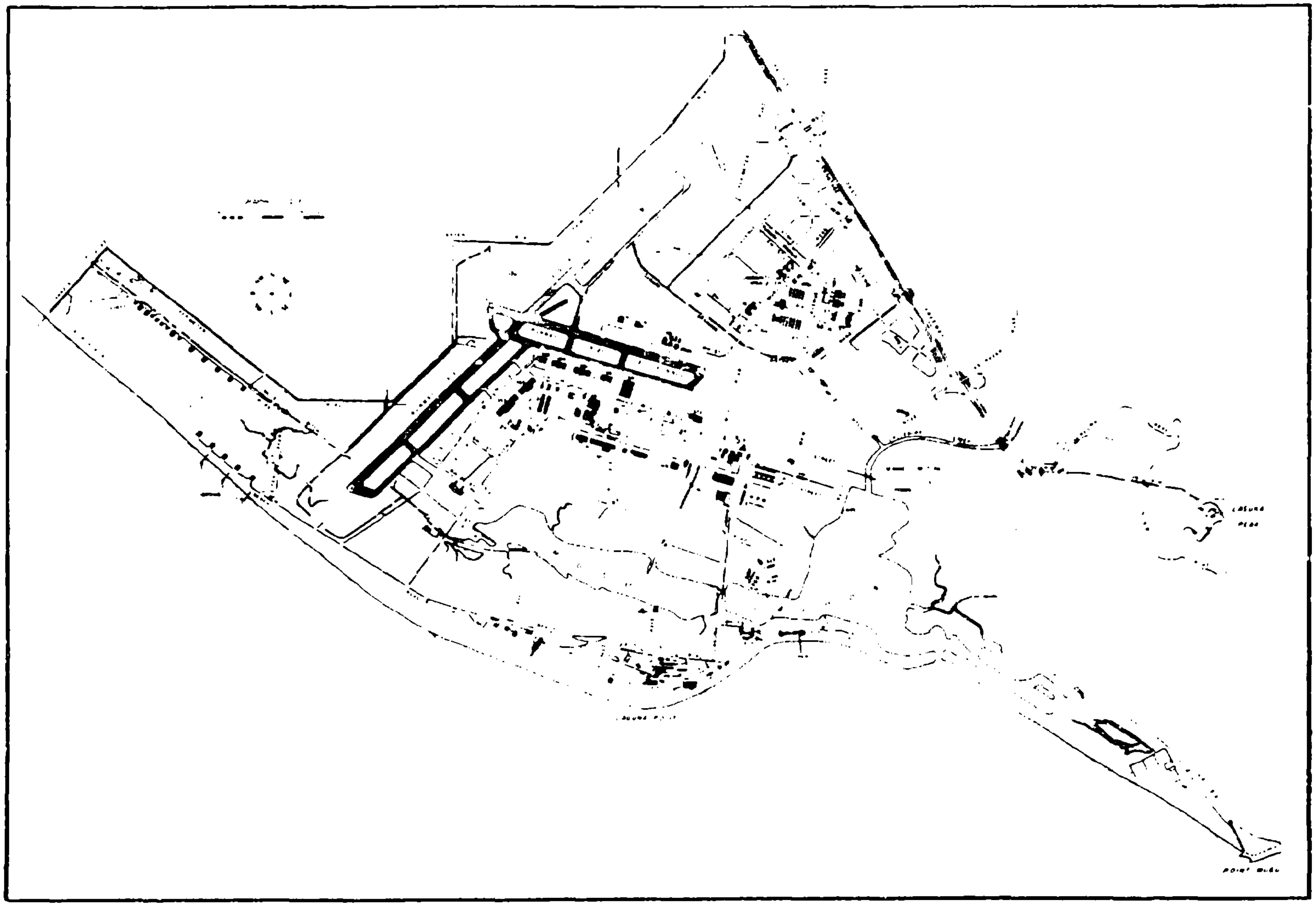

Figure 1-3(b) Detailed Map of Point Mugu Area.

1. [illegible] Weather Center [illegible]
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3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
9. ARCAS [illegible] HASP [illegible]
10. [illegible]

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weather station is located at an altitude of 564 feet which is about 65 feet above the runway but some 340 feet lower than the island's high point. The island's longest dimension is aligned with directions WNW to ESE which is also quite close to the mean wind direction, northwest. Most of the island is exposed rock and soil, and vegetation is rather sparse.

Instrumentation

Observational and climatological data at Point Mugu and San Nicolas Island are obtained from the following sites:

Point Mugu

1. Flight-safety equipment consists of the AN/GMQ-10 transmissometer and AN/GMQ-13 cloud-height set (rotating beam ceilometer) which are located at both ends of runway 03-21. A runway visual range system computes and displays runway visual range in 100-foot increments both day and night.

2. Airfield observational equipment consists of the AN/UMQ-5D wind system and the AN/GMQ-14 semiautomatic weather station for ambient temperature and dewpoint, and is situated near the runway intersection.

3. Autographic recordings of the above measurements, as well as recorded winds, temperature, and dewpoint at Laguna Peak are available in the PMR Weather Center. Visual and recorded readouts of ballistic wind data from the launch pad at 44 and 85 feet MSL are also available.

4. Rawinsondes and rocketsondes released at the beach transmit upper-air data to the receiving stations at the Weather Center from peak heights of 32 and 60 km, respectively. A CDC-3100 computer is used for processing the data into useful format.

5. A satellite readout station for receiving, recording, and displaying APT (automatic picture transmission) weather satellite data is located within the Weather Center.

6. Other important routine and operational instruments are the tipping bucket raingage located about 200 feet north of the Weather Center, wave and water-temperature recorders located at the beach, and airborne refractometers mounted and flown in range aircraft.

The locations of much of the equipment mentioned above are shown in figure 1-4.

San Nicolas Island

1. Flight-safety equipment consists of the AN/GMQ-10 transmissometer and AN/GMQ-13 cloud-height set (rotating beam ceilometer) which is located

at the approach end of the GCA (ground-control approach) runway (#30).

2. Airfield observational equipment consists of the AN/UMQ-5D wind system and the AN/GMQ-14 semiautomatic weather station for ambient temperature and dewpoint, and is situated at the runway midpoint.

3. The AN/GMD-1B rawinsonde system and recordings of the AN/GMQ-10, 13, 14 and AN/UMQ-5 are located in building 121. GMD rawinsonde systems are also located at the launch complex area and at the western end of the island near sea level to support operational requirements. These systems are supplemented with surface measurements as required.

Unique Problems

Several factors combine to make Point Mugu and most of the southern California coast a unique place in which to forecast weather. These areas experience what is known as a "Mediterranean" climate--a climate characterized by stable, persistent weather regimes marked by infrequent change in perceivable weather from day to day and even month to month. Large-scale synoptic changes during much of the year are infrequent and short-lived. Extremely low temperatures are rarely recorded because of the proximity of the ocean. The ocean results in a near-steady supply of moist marine air to the coast, but this flow is subject to rather pronounced diurnal and local variations of intensity and effects. The mountains, both nearby and relatively distant, have a pronounced effect on the movement and depth of the marine air--sometimes channeling, sometimes blocking, and sometimes heating and forcing air to rise. Islands and sea surface temperature anomalies add their complex effects. The coastal strip forms the boundary separating sea air from land air and therefore experiences more local-scale "weather" in a day than it does synoptic-scale weather in the course of a month or more. This means that conventional synoptic forecasting methods are often less applicable to Point Mugu than mesoscale observations and rules. The interrelation of mesoscale and synoptic patterns is complicated, but the effects on Point Mugu weather are substantial and warrant extensive study. Weather forecasting parameters and rules vary in importance and validity from month to month and with each season, according to the relative importance of synoptic and mesoscale features. The Point Mugu forecaster must therefore rely heavily on tools developed from special local studies concerned with the Point Mugu atmosphere. The PMR forecaster is thus further faced with the dilema that his forecasts must verify better than those elsewhere to demonstrate meaningful forecast skill while having to develop and apply his own non-routine forecast rules and techniques for the local area.

An additional forecasting problem is the general void of conventional data in certain oceanic regions upstream from Point Mugu, the regions from which our weather usually comes. This has been greatly alleviated by high quality APT weather satellite photos received daily at Point Mugu. These pictures help to visualize how the synoptic flow becomes modified by local geography.

CHAPTER 2. GENERAL FACTORS CONTRIBUTING TO LOCAL WEATHER

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CHAPTER 2

WEATHER REGIMES

Just as the sun provides the energy to drive the winds, heat the air and ground, and evaporate water on a global basis, it is the primary influence in local weather each day. Typically, the Oxnard Plain, Point Mugu, and the coastal slopes are heated sufficiently each day to cause the usual morning low clouds to evaporate by afternoon. Large-scale daily heating by the sun of coastal southern California results in daytime sea breezes which cool coastal locations and probably keep pollution levels from being intolerable. Nights permit cooling and a return to calm, generally moist conditions.

Of almost equal importance to Point Mugu and the local area is the ocean which gives rise to a cool, moist marine layer of air which almost always immerses coastal basins including the Oxnard Plain and Point Mugu. Fog, low clouds, drizzle, haze, pollution, cool temperatures, and high humidity are common within this marine air, although these individual characteristics are strongly modified with distance from the sea. The marine layer is displaced from the surface at Point Mugu only by infrequent strong synoptic changes of air mass. In addition to keeping air temperatures near those of the cool water, because sea surface temperatures change only slightly throughout the year, the ocean also supplies nearly all of the water for cloud formation, precipitation, and the dew commonly observed in early mornings. The ocean's coolness, relative to the sun-warmed interior, gives rise to the persistent sea breezes observed on most afternoons.

The third major control on local weather is the topography. The nearby hills tend to contain the marine layer within the Oxnard Plain, just as the topography surrounding the Los Angeles Basin tends to prevent ventilation and replenishment of air in that location. The local hills heat up in the daytime from the sun and help to burn off surrounding low clouds and fog. The heated slopes also help to draw in or induce the afternoon sea breezes but, at night, the cooled slopes lead to land breeze "drifts" which fill the Oxnard Plain with colder air. In addition, the local hills and the Santa Monica Mountains, which stretch east-west along the coast from Point Mugu to Santa Monica, tend to turn southerly winds to southeast and increase their speed. This is particularly

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true during rain situations and in pronounced low-level eddies. Less precipitation falls locally than on the hills, partially as a result of a rainshadow effect caused by the southeast winds descending into the Oxnard Plain. The higher mountains to the north lead to strong orographic lifting and clouds and showers are common there on days when the atmosphere is moist and unstable.

The east-west Santa Ynez and Topa Topa Mountains also lead to formation of eddies within the marine layer downstream over coastal southern California which strongly modify the typical formation and evaporation of local low clouds. The same mountain range often acts as a partial barrier to storms and air masses from the north. These higher mountains combine with the coastal mountains and slopes to form complex channels and gaps through which dry desert air occasionally flows to the coast and brings to Point Mugu and much of coastal southern California the dry, strong, gusty, and frequently warm northeast winds known as Santa Anas.

WEATHER REGIMES

The sun, ocean, and topography combine to cause a generally moist, cool climate at Point Mugu with abundant low cloudiness, hazy conditions, and an alternating land/sea breeze circulation on most days. Local spatial and diurnal variations of weather parameters are usually larger than those observed during typical synoptic events. This does not mean that such synoptic events are unimportant locally: on the contrary, they can produce major changes in PMR operating conditions and even preclude most naval aircraft operations for periods of hours or days.

The skill of a forecaster in a climate characterized by persistence is determined by his ability to forecast correctly the relatively infrequent synoptic changes that do occur. This factor, coupled with the large variations of weather on the mesoscale (subsynoptic) and diurnal time scale, make the Point Mugu and southern California weather forecaster's job a challenge.

The seasons at Point Mugu are not as clear-cut as in most midlatitude continental locations. For instance, the summer is not typically hot or even very warm. The ocean keeps days mild and nights only slightly cooler. The year's hottest weather typically occurs in early fall. Nearly all of the rain and the very dry weather occurs in the same 7-month period of October through April.

A general overview of the weather for each of the four calendar seasons at Point Mugu follows. Monthly summaries of various weather parameters and extremes are summarized in chapter 3. A more comprehensive review of climatological patterns and statistics for Point Mugu and San Nicolas Island is found in the Climatic Handbook for Point Mugu and San Nicolas Island: Volume 1, Surface

Data (reference 2), and Volume 2, Upper-Air Data (reference 3). These volumes contain the time averages of all individual weather patterns and occurrences experienced each year which are discussed in this handbook.

Seasonal Summaries

Summer

During the summer months, a mound of high pressure--the North Pacific Semipermanent Subtropical High--lies over the ocean areas to the west. The clockwise flow of air around the high results in persistent northwest winds over most offshore areas including San Nicolas Island. South of Point Conception along the immediate coast, the sea breeze component makes the wind more westerly or southwesterly during midday hours. The general northwest flow is enhanced by the presence of a heat-induced surface "thermal trough" of low pressure which extends from Mexico to Oregon over the interior desert regions. In addition, the air flowing around the eastern portion of the subtropical high subsides from above (at the 700-mb level at about 0.5 cm/s) in midsummer (reference 4). As this air sinks, it heats up at the adiabatic rate of about 5.5°F per 1,000 feet of descent so that it arrives at low altitudes as a warm, dry air mass. The transition layer between the warm, dry air above and the cool, moist marine air below is known as the subtropical inversion or, more simply, "the inversion" (references 4 and 5).

The stratus and fog which forms within the marine layer and spreads over Point Mugu, San Nicolas Island, and most of coastal southern California nearly every day, gives rise to the name "stratus season." Pollutants and smog are often trapped within the marine layer by the stable inversion above it, and the effects are worst when the contaminated layer is shallowest. The depth of the marine layer and the height of the inversion are observed to vary simultaneously.

Stratus and fog are almost a daily occurrence at Point Mugu; they occur primarily during the night and morning hours and break up under the heat of the sun around late morning or early afternoon. Drizzle frequently falls in the morning when the stratus is thickest. Toward the end of the summer, the low clouds and fog break at an earlier hour than at the start of the summer; presumably this is related to the effects of warming of the ocean surface and to periods of increased subsidence. The monotony of the summer weather is almost unbroken because the storm track is far to the north. There are, of course, weak upper troughs or lows which traverse the area from time to time, but these usually do no more than temporarily lift the inversion and modify the marine layer and stratus. On a few days every summer, tropical air will be advected into the area at mid and high levels and may result in middle and high clouds or possibly light showers in the area.

Fall

During the transition season of fall, stratus becomes less prevalent at Point Mugu. As high pressure builds into the Great Basin, the first large-scale offshore flows or Santa Anas may develop and bring the year's most severe episodes of heat and smog, usually during October. The storm and belt of upper westerlies gradually move farther south, and passing disturbances may result in frontal passages that produce showers or rain. Great instability sometimes arises when the first cold trough deepens over still relatively warm ocean waters and results in quite heavy rains, often during mid-November. With each passing storm, the subtropical high shrinks or becomes displaced, the inversion lifts and either weakens or becomes destroyed, and any stratus present is either dissipated or transformed into a more unstable cloud form. As fall merges into winter, so do the characteristics of Point Mugu weather.

Winter

Winter weather at Point Mugu is not severe but there is considerably more change in weather than during the warmer months. Cold troughs and their counterparts, surface frontal systems, usually pass the local area with some regularity, force the subtropical high to shrink or to be replaced in the process, and produce light to sometimes heavy precipitation. As the onshore pressure gradient reintensifies after frontal passage, strong surface winds and clearing weather often follow. Occasionally, troughs will stagnate or deepen just off the coast, and inclement weather will continue. In between these periods of "trough" weather, Point Mugu may be influenced by warm ridges aloft and if there is a buildup of surface pressure in the Great Basin, the result will be dry Santa Ana winds at Point Mugu. These may cause abnormally high temperatures at Point Mugu, but temperatures in winter average less than those in summer. Fog, low clouds, and other weather typical of the summer may also occur in winter whenever the Pacific High, subsidence inversion, and moist marine layer are present, but not with the regularity of the stratus season.

Spring

Spring is a transitional season at Point Mugu; however, on the average, spring seems to be cooler, more unstable, and cloudier than fall. It is windier, too; March and April have the greatest frequency of windy days of any month. Cold lows seem to have a higher frequency of occurrence during this season, and surface fronts are often followed by a period of very brisk westerly winds, especially in the Sea Test Range and the Channel Island areas. Precipitation with fronts becomes much less frequent and less intense by midspring as the subtropical high reintensifies and the belt of strong westerlies aloft are found

at high latitudes. Surface ocean waters are relatively cold during this season and help to keep the surface air cool. By mid or late spring, fog, low visibility, and stratus or stratocumulus become more frequent, and indicate the approach of summer.

It is apparent from the preceding calendar or "seasonal" descriptions that there are three dominant major weather regimes. One is the low cloud or stratus regime which runs from late spring through early fall on a more or less continuous basis but also at other times throughout the year; the second is the Santa Ana regime which brings dry northeast winds to the local area sporadically from early fall through midspring; and the third is that of fronts and other rain-producing features, which like Santa Anas, are transient and most significant in the same fall through spring period. Subsequent discussion is arranged around these three major weather regimes.

CHAPTER 3. STATISTICAL AND CLIMATOLOGICAL RECORDS

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CHAPTER 3

STATISTICAL AND CLIMATOLOGICAL RECORDS

Climatological data on various meteorological parameters are available for Point Mugu and San Nicolas Island dating back to 1946. These data have been condensed into comprehensive climatologies and are available in references 2 and 3.

A few of the more fundamental statistics are presented in tables 3-1 through 3-4 and figures 3-1 and 3-2 for quick reference and to relate to the individual weather conditions discussed in this handbook.

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Table 3-1. Frequency of VFR Weather (ceiling $\geq$ 1,000 feet, visibility $\geq$ 3 miles)

Percent frequency for year: Point Mugu, 80.5%, San Nicolas Island, 78.7%.

Hourly Reports (PST)	Percent Frequency of VFR Weather											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Point Mugu												
0000-0200	87.6	86.7	89.3	88.1	81.5	68.6	59.5	58.3	65.9	71.7	82.4	83.3
0300-0500	87.4	82.5	87.1	86.4	77.6	59.9	45.6	48.3	59.1	[illegible]	82.2	83.9
0600-0800	86.2	82.2	85.4	84.1	75.5	57.6	42.4	45.0	52.2	63.4	78.1	82.3
0900-1100	86.7	84.2	90.5	90.4	81.6	72.7	69.1	66.8	73.2	75.6	83.4	83.6
1200-1400	89.5	87.6	93.2	92.4	91.9	82.9	81.0	79.1	87.4	85.5	89.8	88.9
1500-1700	91.0	98.7	93.6	94.5	92.7	87.9	89.4	85.0	87.1	88.4	89.8	89.6
1800-2000	90.1	88.5	92.3	92.8	88.5	80.3	80.9	75.2	79.3	83.4	89.4	86.0
2100-2300	88.4	88.2	91.2	90.2	86.2	75.3	73.2	70.3	74.6	78.5	83.6	84.7
All	88.4	86.1	90.3	89.9	84.8	73.1	67.6	66.0	72.4	77.3	84.8	85.3
San Nicolas Island												
0600-0800	83.8	81.6	82.7	75.1	64.9	50.6	37.9	37.0	54.1	65.9	79.0	81.1
0900-1100	85.2	81.5	88.0	82.9	76.9	67.0	62.2	63.5	70.8	78.8	86.2	85.4
1200-1400	87.4	87.8	91.8	90.3	87.0	83.6	84.4	86.1	86.1	89.1	90.6	88.9
1500-1700	87.9	88.4	93.3	90.0	88.2	87.1	87.1	89.5	86.4	88.5	90.1	87.5
All	85.7	85.0	88.5	85.0	77.6	69.7	65.0	66.4	72.1	80.0	85.9	85.6

Notes:

1. Frequencies for San Nicolas Island for the other hour groups are based on less than 15% of the number of observations available for the frequency computations at the hour groups provided here, and thus are not felt to be of comparable validity.
2. Frequencies listed under "All Hours" for each month include the nighttime hours.

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TABLE 3-2

Table 3-2. Frequency of Weather Below PAR (Precision Approach Radar, formerly GCA) Minima

Percent frequency for Year. Point Mugu, 1.8%. San Nicolas Island, 3.3%.

Hourly Reports (PST)	Percent Frequency of Weather Below PAR Minima											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Point Mugu (PAR Minima = ceiling < 100 feet; visibility < 1/4 mile)												
0000-0200	3.4	2.4	2.4	2.7	0.9	1.4	2.3	3.8	4.4	6.3	4.0	4.0
0300-0500	3.4	4.0	3.9	5.0	1.8	2.2	4.5	7.0	6.4	8.2	5.0	3.9
0600-0800	2.1	3.1	2.7	2.8	0.9	1.9	4.1	4.4	5.6	6.4	3.2	2.8
0900-1100	0.5	0.8	0.0	0.2	0.0	0.1	0.0	0.0	0.1	0.4	0.4	1.0
1200-1400	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1
1500-1700	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.1	1.1
1800-2000	0.4	1.4	0.0	0.9	0.9	0.2	1.1	0.2	0.2	2.1	0.8	2.3
2100-2300	1.7	2.4	1.6	1.4	0.3	1.1	1.0	1.4	2.6	4.1	2.1	1.9
All	1.5	1.8	1.3	1.6	0.6	0.9	1.5	2.1	2.4	3.5	2.0	2.1
San Nicolas Island (PAR Minima = ceiling < 100 feet; visibility < 1/2 mile)												
0600-0800	5.5	6.6	3.7	4.9	6.4	10.9	12.0	11.8	7.9	8.0	4.5	6.1
0900-1100	4.5	4.5	1.1	2.0	1.5	1.4	1.6	1.4	1.3	1.5	1.8	4.0
1200-1400	4.5	2.3	0.4	0.5	0.0	0.0	0.1	0.0	0.0	0.2	1.0	3.2
1500-1700	4.0	1.9	0.7	0.5	0.0	0.1	0.1	0.1	0.1	0.6	0.8	3.2
All	5.0	4.0	0.6	1.9	2.7	3.7	4.4	4.1	3.3	3.0	2.4	4.5

Notes:

1. Frequencies for San Nicolas Island for the other hour groups are based on less than 15% of the number of observations available for the frequency computations at the hour groups provided here, and thus are not felt to be of comparable validity.
2. Frequencies listed under "All Hours" for each month include the nighttime hours.

Table 3-3. Point Mugu Surface Climatological Data

Month	Temperature (°F)				Precipitation (In.)			Humidity (%)			Surface Winds (Kt)			Mean Sky Cover (Tenths)
	Average		Extreme		Avg Amt	Extreme		Average		Extreme	Prevailing Direction	Avg Speed	Maximum Peak Gust/Yr	
	Max	Min	Max/Yr	Min/Yr		Max/Yr	Min/Yr	Max	Min	Min/Yr				
Jan	62.1	44.0	88 1965*	29 1970	2.57	11 57 1969	0 02 1948	87	47	4/1961	N	4	ENE/47/1966	4.1
Feb	63 0	45 1	89 1971	27 1971	2 01	13 85/1962	Trace/1961*	89	48	2/1955	N	4	NE/38/1966	4 3
Mar	62 3	45 1	87/1951	34 1966*	1 21	4 52 1958	0 00 1959	92	53	3/1956	W	9	W/43/1964	4 4
Apr	63 4	48.2	99 1966	34 1955	0.97	4 23 1965	Trace/1970*	94	60	16/1969	W	10	W/50/1964	4.2
May	64 8	51 3	96 1970	39 1950	0 13	0 99/1955	Trace 1970*	93	63	8/1960	W	8	NE/39/1967	4.8
Jun	67 1	54.2	100/1957	43 1955*	0.03	0 26/1963	Trace 1970*	95	67	9/1957	W	8	W/29/1965*	5.8
Jul	69 8	56 8	88 1960	41 1948	0 01	0 13 1969	0 00 1947	96	69	34/1960	W	7	SSE/27/1967	5.1
Aug	71 4	57 1	95/1955	46 1948	0 01	0 12/1947	0 00 1949	96	68	30 1959	W	8	W/24/1968	5.1
Sep	71 6	56.6	97 1965*	39 1948	0.06	0 57/1963	0 00/1957	94	64	5/1958	W	7	NE/37/1965	4.8
Oct	69 9	52 8	104 1971	38 1949	0 19	0 90/1957	Trace 1969*	93	61	7/1958	W	7	ENE/43/1967	4.4
Nov	67 8	48 9	98/1965	31/1958	1.85	6 42 1965	0 00 1956	88	47	4/1961*	N	4	ENE/41/1969	4.7
Dec	64 1	45.6	89/1958	28/1971	1.51	4 13/1951	0 05 1962	83	43	3/1959*	N	4	ENE/42/1968	4.0
Year	66.4	50 5	104 10 71	27/2 71	10.56	21 87/1961-62	4 82/1958-59	92	58	2/2/55	W	8	W/50/4/64	4.6

Notes - *Also occurred in earlier year or years. Periods of record for averages and extremes follow name of item below.

Temperature Averages, Jan 47 - Dec 70. Extremes, Mar 46 - Dec 71.

Precipitation Averages, Jul 46 - Jun 71, Extremes, Jul 46 - Jun 71. A trace is an amount too small to measure (< 0 01'').

Maximum rainfall in one season (1 Jul - 30 Jun) is 21 87'' in 1961-62, minimum is 4 82'' in 1958-59.

Humidity Averages, Jan 52 - Dec 64, Extremes, Jan 52 - Dec 65 All months have reported 100% relative humidity.

Surface Wind Averages, Jul 62 - Dec 68, Extremes, Jul 62 - Dec 69 Prevailing wind direction and average wind speed are the most frequently observed wind direction and the average speed from that direction (In July 1962, the AN/UMQ-5 wind equipment was relocated from tower locations near 100 feet MSL to the present runway location at 26 feet MSL. Reported surface winds since that date are substantially lower than those recorded in earlier years due to this relocation and because they are considered more representative of true surface conditions, only this later period of record has been used in this table)

Sky Cover Averages, Jan 60 - Dec 69. Zero-tenths is clear, ten-tenths is overcast.

TABLE 3-4

Table 3-4. San Nicolas Island Surface Climatological Data

Month	Temperature (°F)				Precipitation (In.)			Humidity (%)			Surface Winds (Kt)			Mean Sky Cover (Tenths)
	Average		Extreme		Avg Amt	Extreme		Average		Extreme	Prevailing Direction	Avg Speed	Maximum Peak Gust Yr	
	Max	Min	Max/Yr	Min/Yr		Max/Yr	Min/Yr	Max	Min	Min/Yr				
Jan	58.8	46.0	84/1962	33/1949	1.51	4.61/1952	0.37/1963	86	59	15/1969	NW	13	W/40/1949	5.0
Feb	60.2	49.2	80/1965	39/1959	1.29	5.45/1962	Trace/1961	86	60	18/1965*	NW	14	NW/50/1948	4.8
Mar	59.8	48.2	79/1960	34/1950	0.83	3.12/1958	0.00/1959	87	60	10/1955	NW	16	WNW/40/1949	4.8
Apr	62.3	50.2	96/1968	38/1948	0.71	2.68/1965	Trace/1962	87	60	10/1955	NW	16	NW/36/1951*	5.1
May	62.9	51.3	91/1968*	38/1959	0.04	0.25/1956	0.00/1962	89	64	12/1956	NW	17	NW/39/1951	5.0
Jun	65.2	53.7	96/1957	41/1948	0.03	0.16/1951	0.00/1968*	92	66	11/1957	NW	15	WNW/33/1948	5.3
Jul	68.1	55.8	96/1957	44/1951	0.01	0.13/1950	0.00/1964*	93	65	14/1963*	NW	12	NW/31/1948	5.2
Aug	68.8	56.8	95/1967	48/1953	Trace	0.02/1953	0.00/1964*	94	65	17/1965	NW	13	NW/30/1962	5.1
Sep	70.4	57.8	105/1955	46/1948	0.04	0.44/1963	0.00/1964*	88	59	8/1958	NW	13	NW/32/1957*	4.1
Oct	67.8	55.9	100/1950	45/1949	0.18	1.61/1957	0.00/1965*	88	62	13/1965*	NW	13	NW/32/1960*	4.4
Nov	65.4	53.1	89/1949	38/1958	0.97	5.62/1965	Trace/1959*	83	54	8/1959	NW	13	N/42/1948	3.7
Dec	61.5	50.6	86/1958	38/1966	0.88	4.20/1951	0.00/1953	84	58	8/1958*	NW	13	NW/38/1947	4.5
Year	64.3	52.4	105/9/55	33/1/49	6.49	13.49/1951-52	2.89/1953	88	61	8/11/59*	NW	14	NW/50/2/48	4.7

Notes - *Also occurred in earlier year or years. Periods of record for averages and extremes follow name of item below.

Temperature. Averages, Jan 47 - Sep 65. Extremes, Jan 47 – Jun 68.

Precipitation. Averages, Jul 49 - Jun 65. Extremes, Jan 49 – Jun 68. A trace is an amount too small to measure (< 0.01").

Maximum rainfall in one season (1 Jul - 30 Jun) is 13.39" in 1951-52, minimum is 3.85" in 1963-64.

Humidity. Averages, Jan 55 - Sep 65. Extremes, Jan 55 - Dec 65. All months have reported 100% relative humidity.

Surface Wind. Averages, Nov 47 - Oct 63. Extremes, Nov 47 - Oct 63. Prevailing wind direction and average wind speed are the most frequently observed wind direction and the average speed from that direction. Maximum wind velocity is the highest sustained wind speed and its direction, momentary gusts have exceeded these values to a peak of 64 knots (Feb 48).

Sky Cover. Averages, Nov 47 - Oct 63. Zero-tenths is clear, ten-tenths is overcast.

FIGURE 3-1

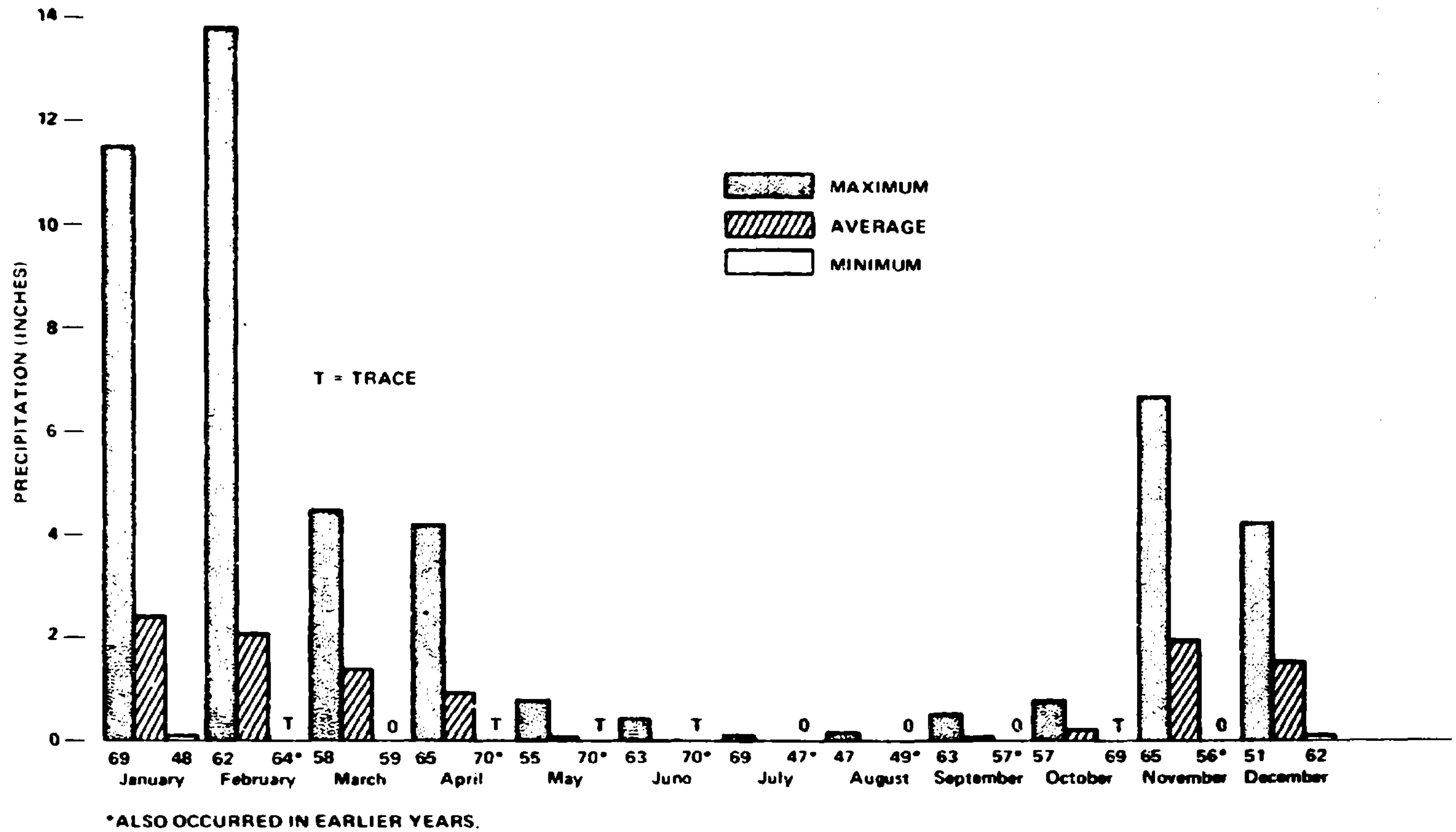

Figure 3-1. Precipitation Data for Point Mugu, July 1946 - Jun 1971.

FIGURE 3-2

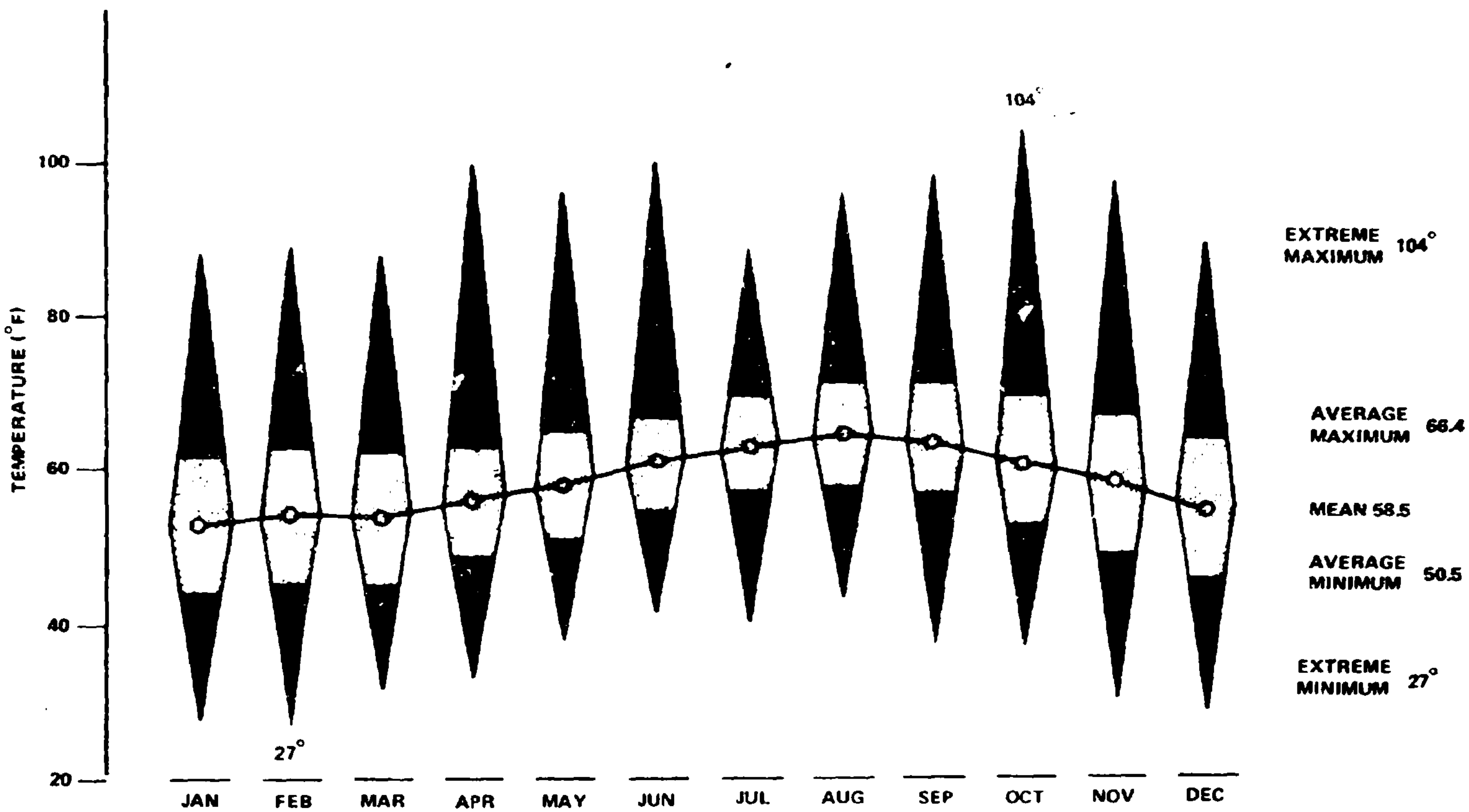

Figure 3-2. Temperature Data for Point Mugu, 1947 - 1971.

PART II. PERSISTENT WEATHER REGIMES

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CHAPTER 4. STRATUS AND FOG

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CHAPTER 4

STRATUS AND FOG

As defined in the Glossary of Meteorology (*reference* 6) "stratus" is a low, greyish cloud with a rather uniform base from which no precipitation other than occasional drizzle or snow falls. At Point Mugu and over all of coastal southern California where mild temperatures preclude any frozen precipitation from this cloud, stratus is the most frequently observed cloud. From April to October, stratus and accompanying fog and haze are so prevalent that this period has been appropriately named the "stratus season." The combination of low ceilings and poor visibilities caused by stratus weather frequently leads to severe curtailment of PMR range operations. Photographs of local typical stratus conditions appear in appendix E.

Onset of Stratus and Fog

At Point Mugu, onset of stratus is observed when the low greyish clouds either move inland from the ocean or form overhead in generally hazy skies. The first process is simply "advection" where already cloudy, saturated air is moved by the wind from its ocean source into the local area. (Fog bands and dense low stratus often seem to advance with a sudden surge in the strength of the sea breeze.) The second process responsible for stratus onset is "formation," where the moist, cool air containing abundant condensation nuclei (the marine layer) cools further and, when saturation is reached, stratus clouds appear. Sometimes the air is already sufficiently cool but stratus does not appear until there is an influx of sufficient numbers of condensation nuclei such as occurs from smog. Most often, stratus onset is a result of both advection and formation, and it becomes very difficult to establish the relative importance of one over the other. However, smoggy or polluted air does appear to favor the process of formation by allowing condensation at lower relative humidities than would otherwise occur (reference 7).

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To forecast stratus onset or occurrence, it is necessary to become familiar with the various synoptic and mesoscale features or influences which permit stratus clouds to form. These are discussed in the following sections.

Pacific High

The semipermanent subtropical Pacific High is a large mound of high-pressure air which frequently covers the northeast Pacific oceanic areas. Its exact position and intensity are variable, especially in winter, but it is nearly always recognizable on weather maps. In terms of weather it is extremely important, for it deflects storms and produces a prevailing onshore flow of moist Pacific air into the Point Mugu area at the surface. At higher levels, it produces subsidence of warm, dry air which restricts the marine air to the lowest few hundred or few thousand feet above the surface (reference 4 and 5). It is within this moist or "marine" layer that stratus forms and dissipates. As marine air cools through mixing, radiation, or other means, condensation of moisture occurs on numerous salt and pollution particles to form clouds. When the Pacific High is well established and a general northwest flow prevails over most of the California coast, conditions are best for the establishment of a marine layer and stratus at Point Mugu. Figure 4-1 is a satellite picture received at Point Mugu, showing extensive but typical stratus cover along the California coast. Figures 4-2 and 4-3 show surface and 500-mb (millibar) analyses made the same day by the National Meteorological Center.

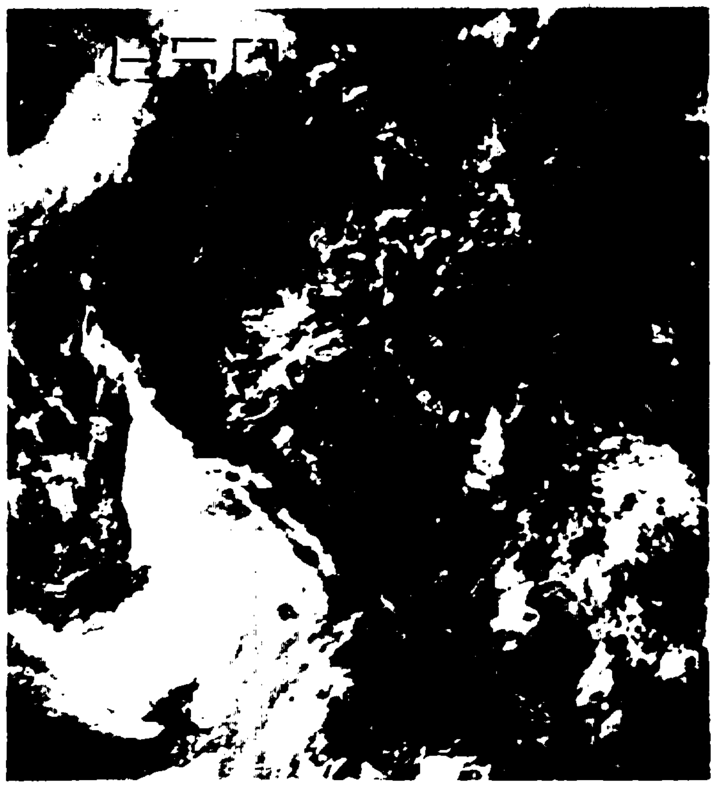

Figure 4-1. Typical Stratus Cover Along California Coast as Photographed by ESSA 8, 1727-1749Z, 26 July 1970.

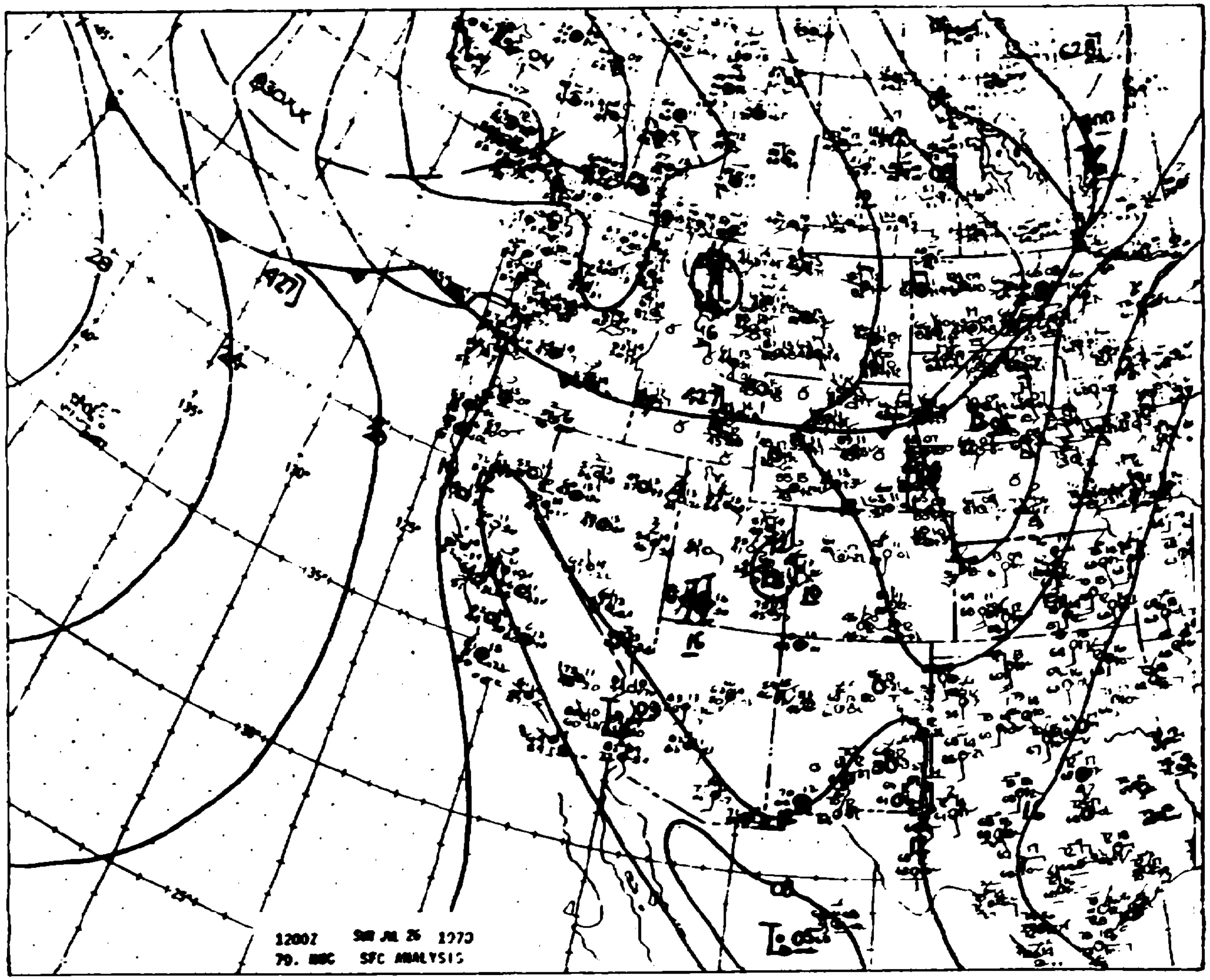

Figure 4-2. Surface Analysis for 1200Z, 26 July 1970.

FIGURE 4–3

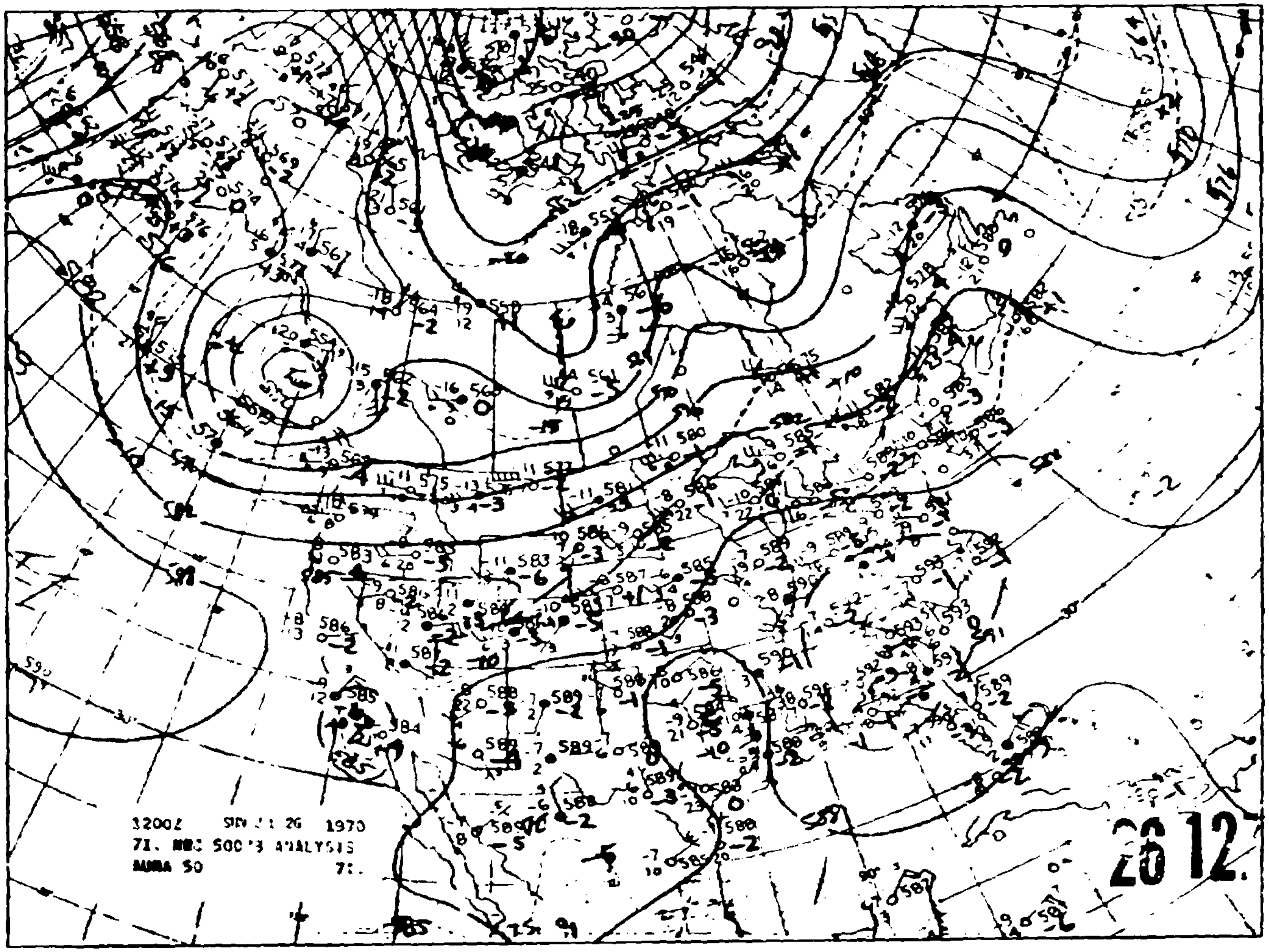

Figure 4-3. 500-Millibar Analysis for 1200Z, 26 July 1970.

Inversion

A pronounced temperature inversion usually forms the transition layer between the cool, moist marine air below and the subsiding, warm, dry air above (reference 5). The effect of the inversion is to form a stable stratification of air which severely restricts upward transport and mixing of water vapor, nuclei, and pollutants out of the denser marine layer. The inversion base generally marks the upper limit to mixing within the marine layer and also often marks the top of the stratus clouds which form within the marine stratum. Vertical growth or shrinkage of the marine layer is associated with a lifting and lowering of the inversion. The future height and thickness of stratus may often be estimated by noting the trend of inversion height as deduced from rawinsonde data or other synoptic reasoning. Recently it has been shown that radiational cooling from the top of the stratus deck likely aids in strengthening the inversion and that the strong, dry inversion in turn provides a measure of stability for the stratus beneath it (reference 8).

Orientation of Isobars and the Thermal Troughs

With the establishment of a strong, persistent Pacific High off the west coast, isobars often appear to parallel the coast (see figure 4-2). Such an orientation frequently accompanies the presence of stratus so that forecasters have come to rely on such a pressure alignment as an indication of a stratus situation. It is difficult to explain the presence of stratus solely on such an isobar orientation, however. With parallel isobars, coastal winds will be directly onshore since the normal cross-isobaric flow is only about 20 to 40 degrees. One can reason that this is not too critical, since large-scale airflow from the northwest with even a partial onshore component will still have an oceanic origin in most instances, and, furthermore, the local sea breeze effect results in more nearly onshore flow at coastal locations during daytime hours. But stratus occurs mainly at night and morning hours when there is no sea breeze, and there are many occurrences of even daytime stratus when the isobars are not parallel to the southern California coast. It therefore appears that the normal isobar orientation is only an indirect indication of other stratus-producing features and should by no means be relied on as a sufficient and necessary feature for the occurrence of stratus.

The same can be said for the Thermal Trough which, together with the Pacific High, results in the frequently observed parallel isobar orientation. This trough is a heat-induced surface low-pressure area that often extends northwest-southeast over the Great American Desert of the southwest United States and northwest Mexico (see figure 4-2). It is caused by hot, light air that results from intense daytime heating over sandy and rocky desert areas. During the summer, when the heating is most intense, the thermal trough is best established and most effective in strengthening the onshore surface pressure gradient

and in causing the isobars to parallel the coast. Any correlation of stratus occurrence and the intensity of the thermal trough should not, however, be explained in terms of isobar orientation, but should be considered indicative of the general synoptic weather situation. Furthermore, localized pressure distributions and wind patterns appear to be of great importance in explaining stratus occurrence at particular coastal locations.

Sea Surface Temperatures

The effects of sea surface temperatures upon stratus are varied. Due to the stress of a prevailing northwesterly wind upon the sea surface, there is upwelling of cold water near the coast which, with the cold California current farther offshore, cools the flow of marine air. This cooling tends to lower the inversion and permits condensation of very low stratus or fog, as shown in figure 4-1. However, the formation of more typical, higher stratus seems to benefit from enhanced turbulent mixing caused by warmer oceanic surfaces farther downwind (figure 4-4) (reference 9). These are plausible explanations, but it has never been satisfactorily determined whether it is warm water or cold water that is conducive to stratus formation. It may be that formation of low clouds--fog, in particular--is more sensitive to the sea surface temperature gradient rather than the temperature itself. However, it would be difficult to explain long-term trends of fog incidence on small temperature gradients when it is known that the near-shore sea surface temperature itself often fluctuates by several degrees (Celcius) over periods of 1 or 2 days throughout the stratus season (reference 10). Similar large fluctuations have been observed at Point Mugu. It appears that there must be a number of factors related to the sea surface, all of which affect stratus and fog formation in varying degrees, depending upon the state of the lower atmosphere. Most likely, sea surface temperatures have their greatest effect on stratus and fog when the marine layer is very shallow. Other detailed aspects of sea surface temperatures, as they relate to west coast· cloud cover have verified the difficulty in determining the true role of sea surface temperatures in stratus formation (reference 11).

Weather Associated With Stratus and Fog

Ceilings, Clouds

When stratus covers the sky at Point Mugu, ceilings are usually quite low and they frequently restrict flying and other operations at the Pacific Missile Range. One of the distinguishing characteristics of these low ceilings is their indefinite nature. Frequently there is so much haze beneath the base of the clouds that it becomes difficult to determine where the base is, whether ceilometer traces or just plain eyesight are used. The moist air in the marine layer does not even require complete saturation for cloud formation

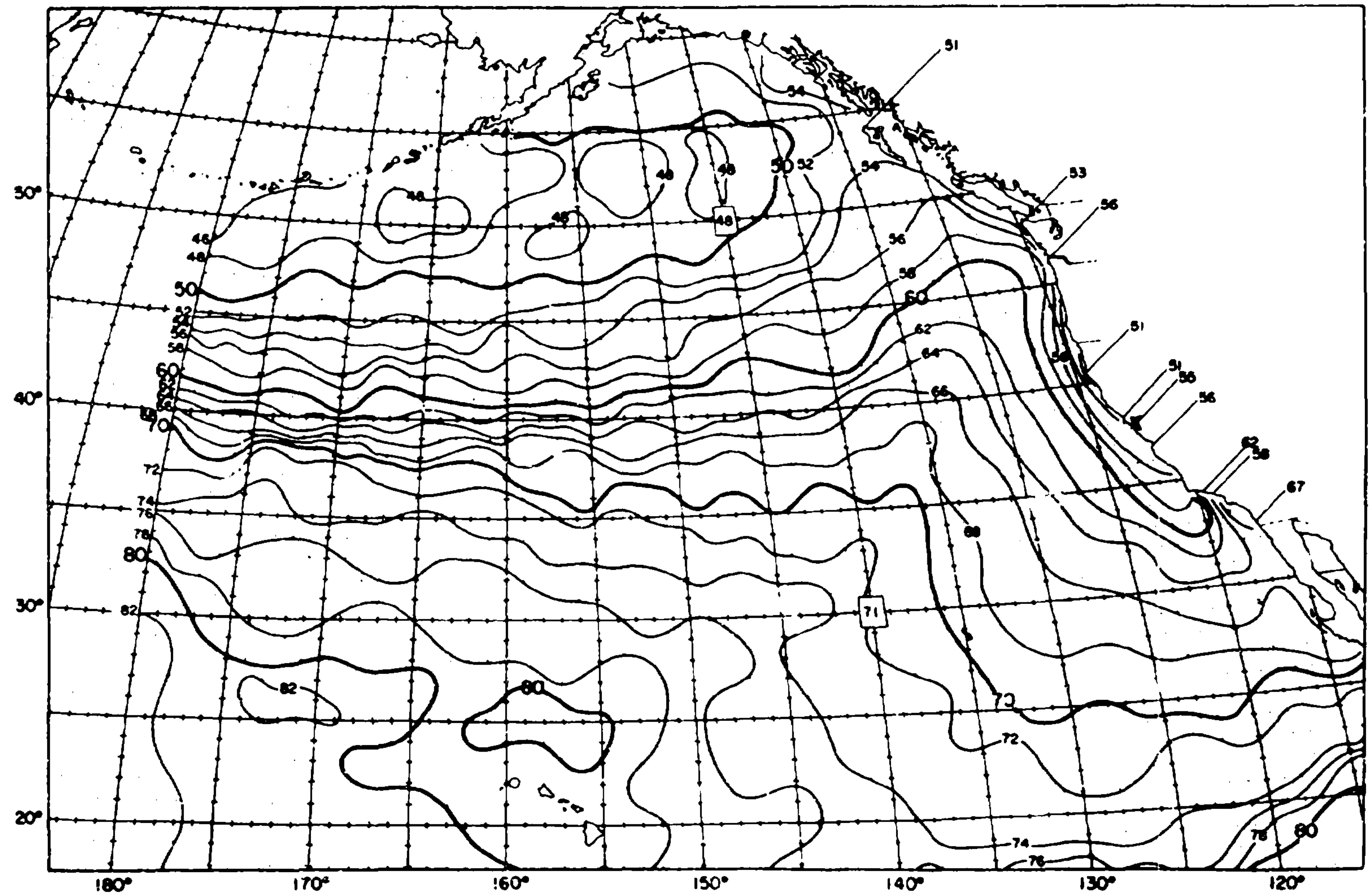

Figure 4-4. Mean Sea Surface Temperature, East North Pacific Ocean, July 1970 (Reference 9).

because of the numerous pollutants and particulates normally found in the air over southern California (reference 7). Coupled with a generally high relative humidity, Point Mugu marine air is frequently in various stages of cloud formation and dissipation.

Frequency of Occurrence: Stratus is not normally present in uniform amounts throughout the stratus season. The frequencies of overcast and cloudy skies for all months show a relative minimum of occurrences in March, a peak in July and August, and a minimum again in November (reference 12).

One of the dominant features of stratus is the diurnal nature of its presence. These clouds are much more frequent at night and early morning than they are in the afternoon. This is exactly the opposite of the cloud pattern noted at most continental stations where daytime solar heating results in an afternoon maximum of convective cloudiness. At Point Mugu, the greatest frequency of overcast skies occurs at 0700 (see figure 4-5). Broken skies have their greatest frequency at noon, and scattered conditions are most frequent at 1400. From these statistics one can infer the usual stratus season characteristics of cloudy mornings and partially sunny, hazy afternoons.

Another feature of stratus is that its formation is a slower process than its dissipation. It frequently takes many hours for stratus to form a complete overcast, whereas it generally takes only a few hours for an overcast sky to dissipate and result in scattered or clear conditions. Of course, on individual days, this pattern may be reversed. On many days, stratus lasts all day and on others it is absent all day, depending on the synoptic and local meteorological conditions.

As the peak of the stratus season is approached, mornings generally become cloudier and afternoons clearer so that the greatest and least cloudiness of the average year occur just a few hours apart in the month of August. Therefore, one may infer that stratus dissipates most consistently and rapidly during this month (reference 12).

Heights: As with the amount of stratus and the frequency of occurrence, stratus heights also undergo variations of both a seasonal and diurnal nature. We note, for instance, that early in the stratus season, average ceilings at Point Mugu tend to be higher and longer lasting than in midsummer. We also note that stratus during mornings is frequently lower than during afternoons (reference 12). Typical heights of stratus cover at Point Mugu are in the range of 1,000 to 2,000 feet. During periods of synoptic influence from cold troughs, pretrough convergence and associated upward motions may result in stratus ceilings that are appreciably higher. During periods of strong subsidence and low inversions, stratus may hover at or just above the surface.

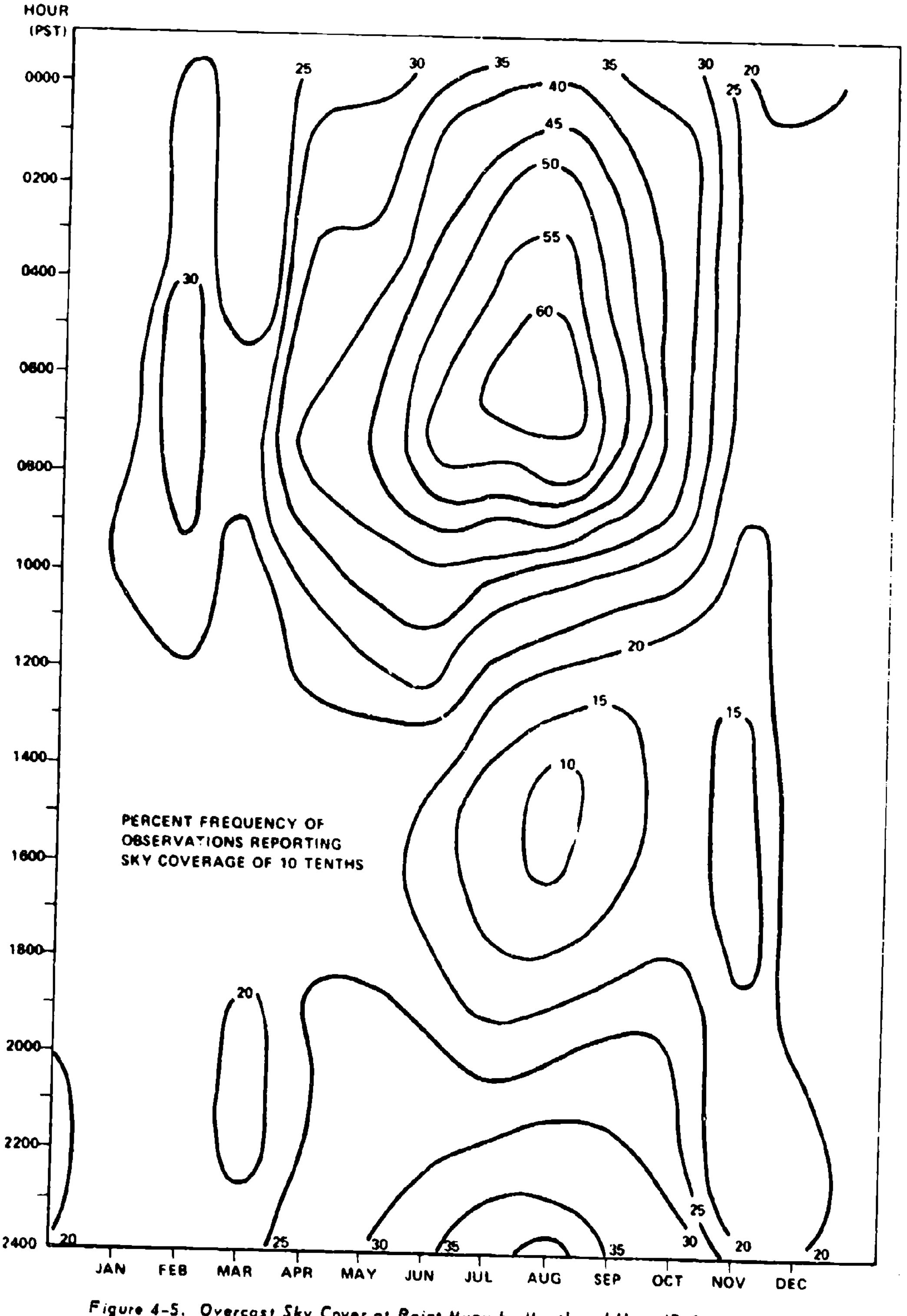

Figure 4-5. Overcast Sky Cover at Point Mugu by Month and Hour (Reference 12).

FIGURE 4-5

Thickness: The thickness of stratus is even more difficult to ascertain than is the ceiling height because there is such a paucity of direct observations. Most estimates, although amplified occasionally by pilot reports, are made on the basis of inversion height information. While stratus may poke through the inversion (reference 13), the base of the inversion is generally a good approximation to the top of the stratus. So, depending on the accuracy of cloud base measurements, the thickness of stratus may be estimated as that distance from the bottom of the stratus to the bottom of the inversion. Tops of stratus decks may also be determined by telephoning personnel on Laguna Peak or at Santa Cruz Island who frequently find themselves looking down at the stratus. In general, about 500 to 1,000 feet seems typical for the thickness or depth of most early morning stratus layers. The thicker the stratus, the darker and more dismal is the weather likely to be below, although this also depends on the density of stratus and the number and size of cloud droplets.

Visibility

Visibility is frequently poor at Point Mugu when stratus is present. Air within the marine layer is usually full of both nuclei and pollutants and is close to the saturation point so that haze, fog, and smog are common beneath the cloud base during stratus situations. Lowest visibilities during stratus weather occur in the early morning. Seasonally, lowest visibilities occur most frequently late in the stratus season (reference 12). Occasionally, following a weak frontal passage, a relatively fresh air mass arrives at Point Mugu from distant oceanic locations to the west and north and the air beneath the stratus is very transparent, and the base of stratus clouds generally appears quite sharp.

IFR Weather and Effects of Stratus on Operations

At Point Mugu, IFR (instrument flight rules) weather (ceilings less than 1,000 feet or visibility less than 3 miles) is most frequent during late night and early morning hours when stratus and visibility are lowest and on a seasonal basis during the months of July, August, and September (reference 12). (See figure 4-6.) "Zero-zero" conditions are most frequent, however, in November. During the afternoons, when stratus and visibility conditions improve, the incidence of IFR weather is markedly less. Tables 2-1 and 2-2 contain more complete climatological summaries of various flight weather conditions at Point Mugu and San Nicolas Island. These have been printed on colored paper to facilitate their use in this handbook.

Drizzle

Drizzle is the only type of precipitation that falls from stratus. Annually, drizzle is reported on 1.6% of observations whereas rain is reported on 1.5% of observations. That it is a frequent "stratus season" phenomenon is shown by the corresponding figures

FIGURE 4-6

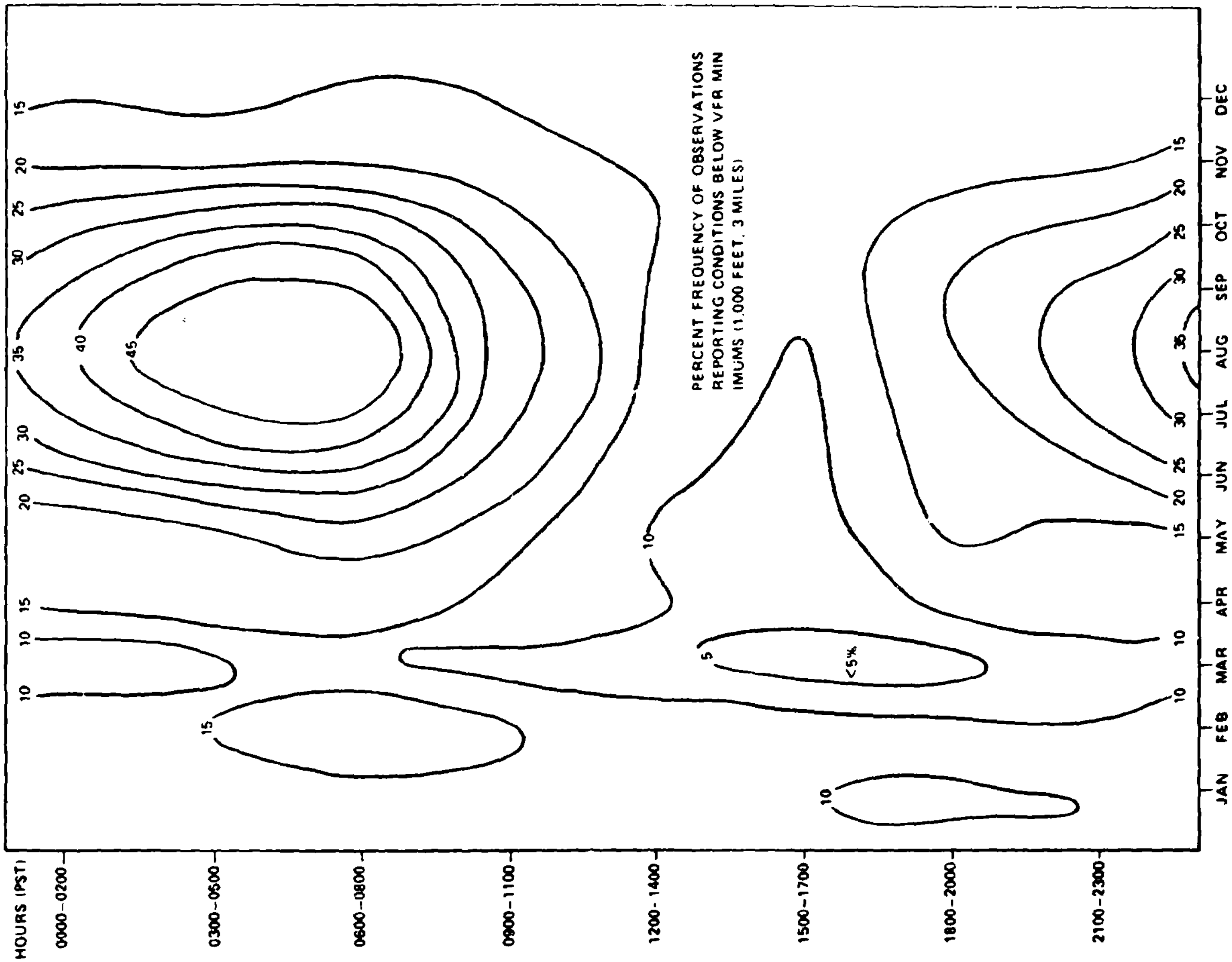

Figure 4-6. IFR Aircraft Minima at Point Mugu by Month and Hour (Reference 12).

for the month of June: drizzle is reported on 3.6% of all observations whereas rain is reported on only 0.1% of observations. During January, the rainiest month, drizzle is reported on 1.2% of observations as compared with 4.4% for rain. The latter figures show that drizzle is much less frequent in winter than it is during the stratus months but it does occur with some regularity even in winter. Winter drizzle, however, is not usually associated with a persistent stratus overcast with clear skies above as it is during the warmer months.

When drizzle occurs, ceilings most frequently reported are in the 100- to 300-foot range. Some of these low ceilings may be due to the drizzle obscuring the real cloud base. Only rarely will measurable precipitation occur with drizzle. The exact prerequisites for heavy drizzle are not known, but drizzle is more likely with thicker stratus, more and larger cloud droplets, and moderate windspeeds within the cloud.

Temperatures

Stratus conditions are normally associated with cool, moist conditions at Point Mugu. As the stratus season progresses and both the atmosphere and sea surface continue to warm, temperatures observed at the surface during stratus cover may rise from springtime 50s and low 60s to late summer high 60s and low 70s.

The warmth or coolness of the lower atmosphere and associated mixing patterns has an important effect on the amount and height of stratus. It has already been pointed out that a strong inversion is favorable to stratus formation because it traps condensation nuclei within the cool, moist, turbulent marine layer below in which stratus formation is possible. But whether the strong inversion is high or low makes a difference. In general, during "cool" periods when a trough is advancing toward the coast, the marine layer may be several thousand feet deep and stratus is usually higher and thicker than normal. Conversely, when the inversion is low (and marine layer is shallow) as when ridging prevails aloft, stratus can be expected to be correspondingly low and thin. During heat wave conditions when subsidence drives the inversion to or near the surface, stratus may not occur at all because of a combination of high temperatures, low humidities just above the surface, and a lifting condensation level that is above the marine layer itself. In addition, very early or very late in the season, deep cold troughs may markedly lift, weaken, or even destroy the inversion and stratus clouds are usually completely evaporated as the marine layer is turbulently modified.

Stratus cover also affects the temperature of the air observed at the surface. When it is cloudy, daytime solar heating is reduced but nighttime radiational cooling is also suppressed. The result is relatively cool days and mild nights when compared with marine air under clear conditions.

Pressure

During the stratus season months, the Pacific High is well established offshore and the thermal trough is likewise observed inland day after day. These features combine to form a persistent onshore pressure gradient over the southern California coast. Synoptic disturbances are too weak to result in marked pressure changes so the semidiurnal tidal pressure oscillation becomes the only discernible feature of pressure change. These synoptically uneventful conditions favor the formation of stratus and result in relatively steady surface pressures at Point Mugu. On a seasonal basis, due to the warmer air of summer, pressures at Point Mugu during the stratus season average 6 mb lower than during the winter months.

Winds

The same two persistent stratus season features, the thermal trough and the Pacific High, result in surface wind patterns which are somewhat different in summer than during the cooler winter months. Northeast winds which are the most frequent and the strongest winds on the average during the months of November, December, and January appear only as weak drainage winds during the early morning hours of the stratus season. During the stratus season west winds are not quite as strong as they are in winter but are more persistent and they occur nearly every afternoon of the warmer months. Southeast winds occur often in late morning and early afternoon during the stratus season as part of the Catalina Eddy circulations and also when land breezes veer to sea breezes.

A striking feature of stratus season winds is the diurnal oscillation between sea breeze in day and a weaker land breeze at night. The ebb and flow plus convergence and vertical motion fields associated with the land- sea-breeze circulation affect the formation and dissipation of stratus through advection and raising or lowering of the inversion. These diurnal effects and changes will be discussed in more detail under "Modification of Stratus and Fog."

It appears that stratus at Point Mugu is very sensitive to changes in the wind and associated changes in inversion, stability, and humidity conditions. A convergent southeast flow associated with a Catalina Eddy may advect, form, and lift stratus over previously clear coastal locations. Early or late season northeasterly Santa Ana winds quickly erode and dissipate existing stratus and fog (see "wind shear," under "winds," Santa Ana section). Forecasters should be wary of these generalized wind relations however, because light northeast drainage flow is usually observed during morning when stratus is most prevalent, and nighttime stratus often is seen moving from the northeast even though it is spreading or forming from the ocean to inland areas.

Under typical stratus weather, offshore areas experience a much more consistent wind picture. These areas are nearly continuously buffeted by brisk northwest winds (see figure 4-7) (reference 14), despite the land- sea-breeze regime experienced at the mainland coast.

As one might expect, when their geographical proximity is considered, upper air winds at San Nicolas Island and surface winds at Point Mugu appear to be correlated (reference 12). Limited studies were conducted using the 5,000-foot winds in June at San Nicolas, and preliminary comparisons showed positive correlations between the two, to permit their use as objective forecasting criteria. Some of the more important results of this study are included in "Thumbrules and Forecasting Aids on Stratus and Fog."

Conditions Over Sea Test Range

Over the Sea Test Range, stratus is characterized by low ceilings and reduced visibilities as on the mainland. In fact, the frequent observations of stratus and fog offshore during summer afternoons indicate that stratus conditions at sea are both more persistent and more severe because of the lack of topographic heating and mixing effects over water that are instrumental in dissipating clouds over land. There are times, however, when stratus is present only along the coast or in small pockets, leaving the ocean clear of clouds. In such cases, satellite photos are extremely helpful in diagnosing whether coastal stratus at Point Mugu is part of a much larger extensive cloud mass (as in figure 4-1) or if it is isolated and therefore presumably more likely to burn off. More detail on seaward spatial variations of stratus is presented later under "Factors That Modify Stratus and Fog."

One of the problems frequently encountered by pilots is the presence of much lower ceilings over the water and at the west end of the runway than are observed over the remainder of Point Mugu. Thus, even though Point Mugu may be officially VFR, low stratus or fog can hover right at the beach and over the sea, presenting severe operational inconvenience or hazard to aircraft. Figure 4-8 illustrates this feature.

San Nicolas Island Conditions

Since the frequency of ceilings below 3,000 feet may be used as a fair measure of the frequency of stratus, it may be concluded that stratus is more prevalent at San Nicolas Island than at Point Mugu because the incidence of low ceilings is greater. Nevertheless, San Nicolas Island is subject to the same synoptic influences as the mainland, as well as some of the same local influences. The windward side of the island where northwest winds impinge upon the island topography is cloudier than the leeside

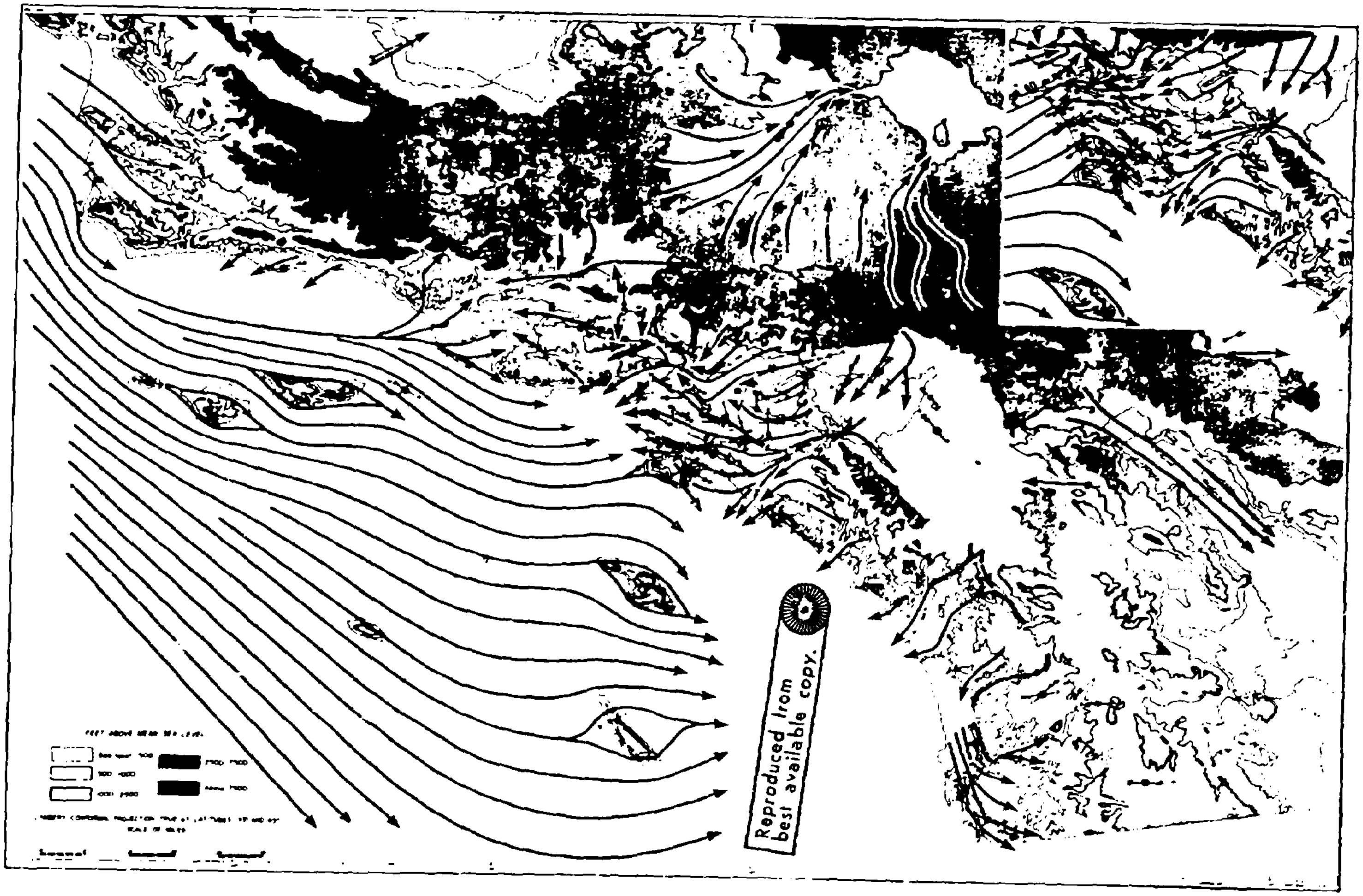

Figure 4-7. Average July Surface Flow Over Coastal and Offshore Regions Between 0000 and 0500 PST (Reference 14).

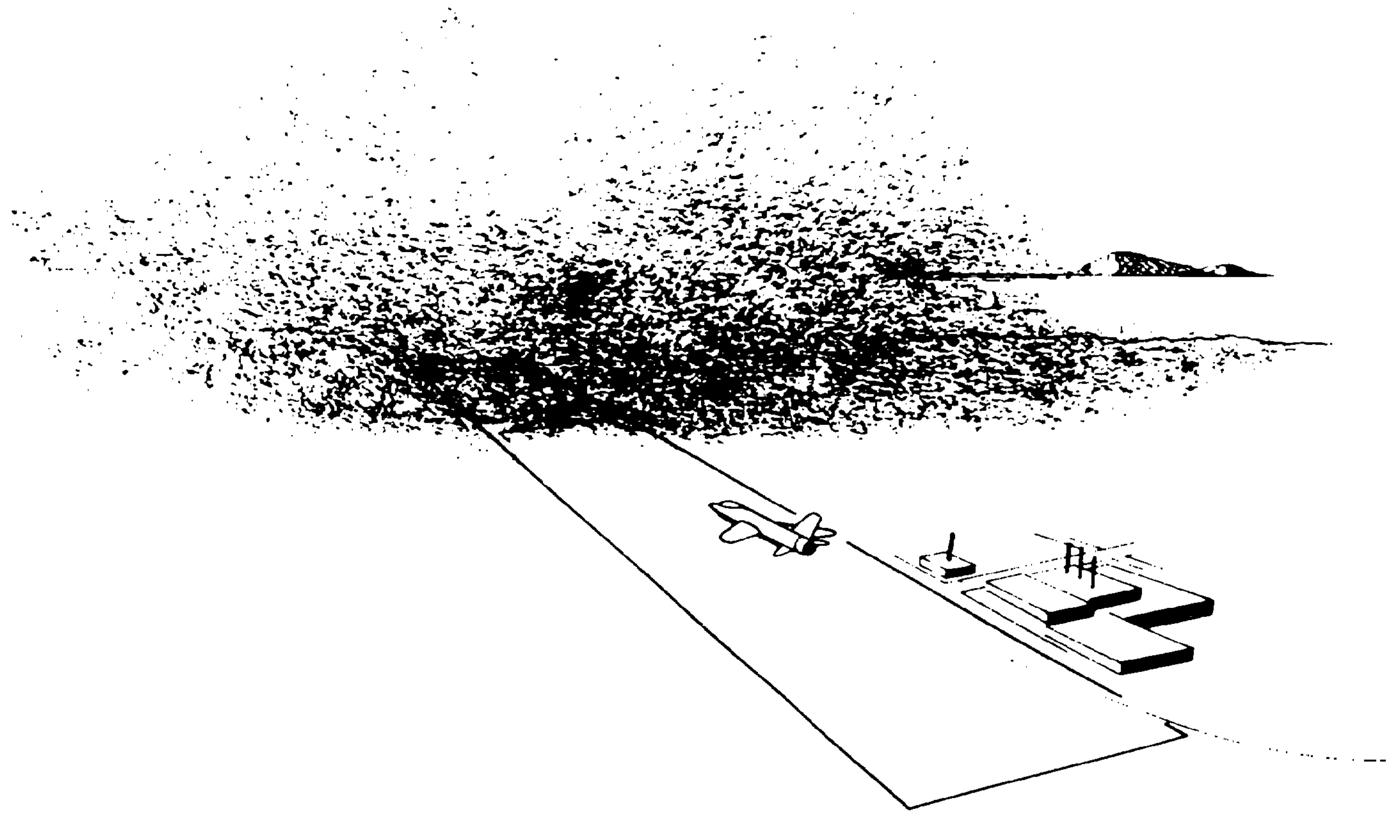

Figure 4-8. Low Stratus and Fog Over Seaward End of Runway While Station is Officially VFR.

where downslope flow apparently causes frequent holes in the stratus. (Fortunately, these downslope areas are also the location of the airstrip and observing site.) Due to the downslope flow and consequent lowering of the inversion and to the elevation of the island's weather station (564 feet), stratus is usually lower at San Nicolas Island than it is on the mainland. An elevated stratus deck over the Sea Test Range can enshroud the station at San Nicolas Island and be reported there as fog. When the station is not engulfed in fog or stratus, a common observation often transmitted on hourly reports is "fog (or stratus) bank surrounding island." This indicates that the island station and higher elevations are above the stratus deck, or that the station is within an opening cleared by downslope flow.

Factors That Modify Stratus and Fog

Diurnal Effects

The daily variation in amount and thickness of stratus is one of the most striking features of the stratus season and is largely due to mesoscale circulations in the lower atmosphere. These diurnal effects dominate all observed fluctuations in stratus cover except for those due to the most abrupt changes in synoptic features. The essence of the diurnal variation of stratus is the daily heating cycle. During the nighttime hours of a typical stratus day, the marine air cools to the condensation point and permits stratus to form overhead and to be advected inland from the sea. The stratus thickens, lowers, and extends further inland so that by sunrise, ceilings are characteristically low, visibility is generally poor because of fog, haze, or drizzle, and IFR weather is at a maximum. The early morning land breeze drift is normally not strong enough to dry the marine air sufficiently to decrease stratus.

Following sunrise of the typical day, solar insolation heats the cloudless interior rapidly, penetrates through the coastal cloud deck at a somewhat slower rate, and the stratus "burns off" from above and below, while the heating in the interior sets into motion the familiar sea breeze. This sea breeze strengthens throughout the morning hours, and reaches a maximum speed during the afternoon. At the same time, the inversion and marine layer are subject to height variations due to systematic diurnal effects and to random and small-scale perturbations in the wind field associated with topographic features. These effects upon inversion height are often quite complicated and individual effects, unfortunately, are cited to explain both sides of various conflicting features of afternoon stratus. Generally, there is an absence of stratus along the coastal strip during the afternoon when the sea breeze is well developed, and visibility and VFR flying conditions improve. Apparently, the coastal clearing usually extends some distance out to sea, but the degree to which this occurs is both highly variable and poorly documented or understood.

Heating ceases during the evening hours, cooling occurs, and the sea breeze gradually gives way to a land breeze. Yet, at the same time, stratus spreads inland from the ocean to the mainland as cooling and condensation occur over land. Depending upon the depth of the marine layer, the stratus may cover only the coastal strip or it may extend inland all the way to the interior mountain slopes. As the condensation level lowers, fog and visibility-restricting haze may form and drizzle may fall from the thickening overcast.

The diurnal cycle of cloudy mornings and sunny afternoons has been illustrated in figure 4-5 which shows the frequency of sky cover by time of day and by month. In August, mornings are cloudiest and afternoons are clearest. Individual stratus season days may vary significantly from the typical example. To confuse the forecaster, some days are stratus-free, some remain cloudy all day, and some are characterized by oscillations between stratus and clear conditions. Occasionally there are clear nights and cloudy afternoons. A more thorough understanding of diurnal effects awaits increased knowledge of the exact role that local topography plays in stratus formation and dissipation.

Seasonal Effects

Descriptive Features: From April to October, stratus is such a persistent and common occurrence at Point Mugu that these months have been aptly called the "stratus season." This does not mean that stratus is absent during late fall, winter, and early spring. But during these cooler months, stratus regimes are frequently interrupted by transient synoptic features which destroy stratus-associated features such as the Pacific High, the subsidence inversion, and the thermal trough. In between these synoptic events, stratus conditions return to Point Mugu as reminder that our seasons do not differ from each other as clearly as black and white. Even during the period of the year when stratus is a persistent feature, we note certain systematic variations in the amount and character of the low cloud. For example, early in the stratus season, average ceilings tend to be higher and longer-lasting than in midsummer when the inversion is typically lower. As the peak of the stratus season is approached, mornings at Point Mugu get cloudier whereas afternoons get clearer. This pattern is similar for visibility so that IFR weather also becomes more frequent in the morning and less frequent in the afternoon as the

season progresses, and the times of maximum frequencies of lowest ceilings and poorest visibilities occur earlier in the day. These tendencies permit "persistence" forecasts during late summer, of cloudy mornings and sunny afternoons, to verify day after day. An interesting point is that the greatest cloudiness and the least cloudiness of the "average" year occur only a few hours apart in August (reference 12.)

Sea Surface Temperatures: Sea surface temperature is one of the parameters often discussed as a stratus factor. At Point Mugu, despite a seasonal warming of the ocean surface from spring to late summer or early fall, waters near the coast are characteristically cool due to the effects of upwelling and the cold California current. It can be argued (and often is) that a warmer sea surface enhances stratus formation by decreasing stability, adding moisture, and stimulating limited convection within the marine layer, or that a cooler sea surface enhances stratus formation by cooling marine layer air below its condensation temperature. Until this conflict of underlying theory is resolved, it is not possible to predict changes in stratus due to changes in the temperature of the ocean surface, especially since the latter are often a result of a marked change in meteorological conditions. As was pointed out under "Onset of Stratus and Fog," the sea surface temperature gradient may also be an important factor (reference 10) but most likely there are a number of factors related to the sea surface which affect and modify stratus in varying degrees, depending on the local state of the lower atmosphere. Thus, it is unlikely that sea surface temperature alone can explain differences in stratus cover such as consistently occur between Point Mugu and the Santa Monica Bay region.

Effects of Synoptic Features

Pacific High and Thermal Trough: During the fall, winter, and early spring, synoptic disturbances are normally both active and frequent and usually result in a marked modification of stratus season features such as the Pacific High and the Thermal Trough. The Pacific High is often displaced and weakened so that it no longer results in a divergent, subsiding onshore flow along the California coast, and the heat-induced Thermal Trough is replaced either by a continental high or by an intense cyclonic circulation. Marked modification of these features

results in an absence of typical stratus. During the stratus season, transient synoptic disturbances are much weaker, more infrequent, and are generally confined to the middle and higher portions of the troposhere so that stratus-inducing features such as the Pacific High and the Thermal Trough are hardly affected. The effects of these weak synoptic disturbances upon summer stratus are subtle, often causing no more than a lowering or raising of the cloud deck or a quicker or slower rate of burning off. In summer, heating of the desert interior is usually considered a positive stratus-producing factor at Point Mugu while cooling of desert temperatures appears to be associated with less stratus at Point Mugu. This does not hold true during the spring and cooler season when deep marine layers associated with active troughs cause both a cooling of the desert and an increase in stratus at the coast.

The Inversion: Transient synoptic features are characterized by troughs and ridges embedded in the general westerly flow aloft. One of the best barometers of the intensity of these troughs and ridges is the height and intensity of the subsidence inversion. Because of the importance of the inversion in trapping moisture and nuclei below for stratus formation and in the development of strong super-refractive layers, it is appropriate to relate inversion trends to the occurrence of stratus and other restrictions to Range operations at Point Mugu. In general, when pretrough convergence increases, the marine layer deepens and the inversion lifts and weakens somewhat, which permits a thicker and higher stratus layer than if the inversion remained low. When the inversion is destroyed or else experiences a height rise of several thousand feet, the marine layer becomes drier and turbulently modified and stratus formation is usually precluded in the well-mixed air. Low, strong inversions result in shallow stratus layers or fog which are easily burned off by the daytime sun. When the inversion is below the condensation level or when it is "driven into the ground" as during periods of moderate subsidence, there is no stratus. These situations are shown in figure 4-9. Some diurnal variations of inversion height affecting stratus due to land- sea-breeze circulations are discussed under "Termination of Stratus and Fog."

Figure 4-10 is a plot of San Nicolas Island inversion heights for 1 year (reference 16). The solid black region defines the inversion layer. In this general picture, the inversion can be seen undergoing large fluctuations throughout the spring, fall, and winter months that correspond to various synoptic periods of storminess and good weather. The peaks and gaps in inversion generally correspond to storm and frontal passages when stratus-type clouds are replaced by cumulus and multilevel cloud layers. When there is no inversion, there is no stratus. When the inversion is low, however, stratus is present at least some of the time. Figure 4-10 shows the inversion to be much lower, stronger and more

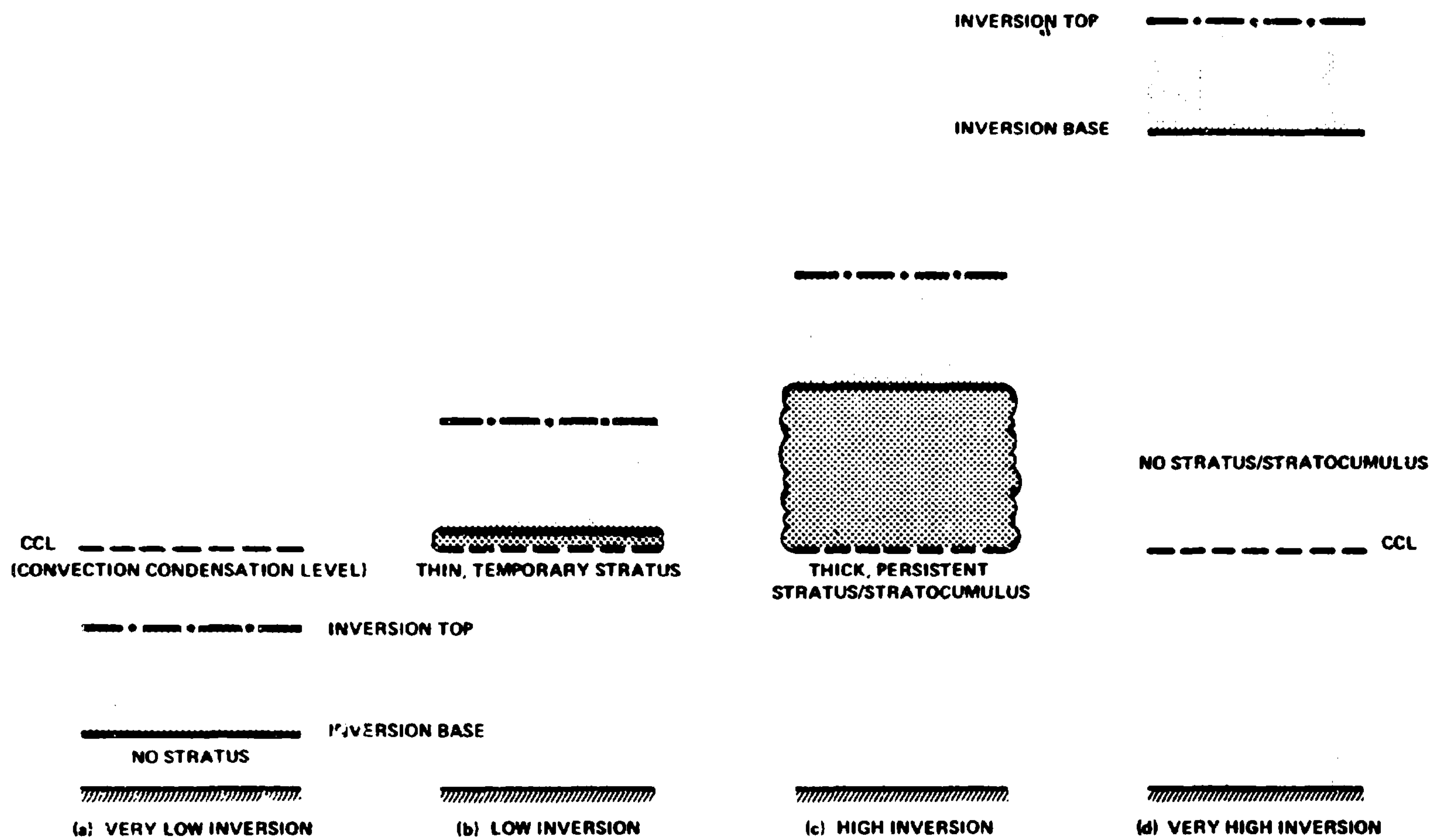

Figure 4-9. Effect of Inversion Height on Local Stratus.

FIGURE 4–10

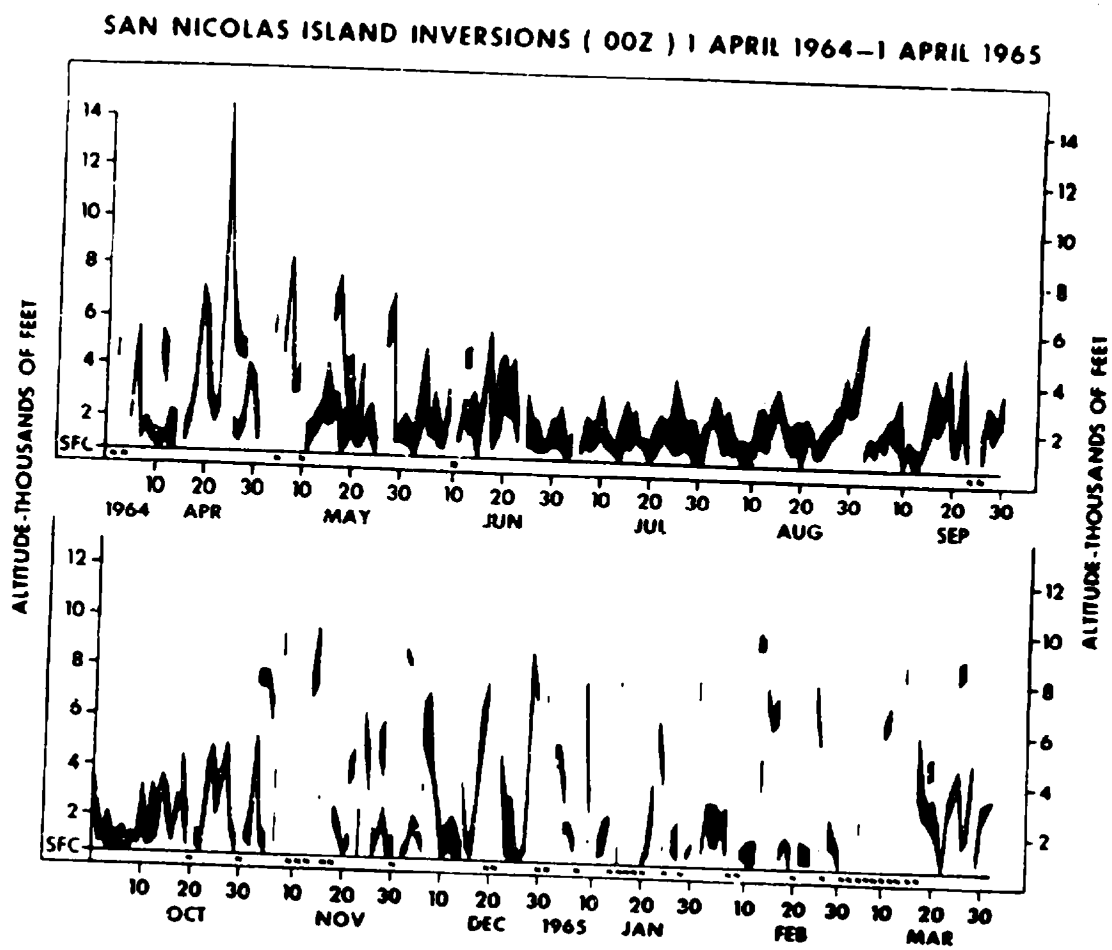

Figure 4-10. Daily Inversion Heights at San Nicolas Island for 000Z, 1 April 1964 Through 1 April 1965 (Reference 16).

persistent during the summer months when stratus is also lowest. The several undulations in summer, with periods of about 1 week, correspond to the passing of weak troughs which usually do no more than lift the heights of the stratus deck temporarily and sometimes cause it to break up at Point Mugu at an hour earlier than usual.

The normal train of events with the approach of a weak summertime trough would be a slight lifting of the inversion and an increase in the height of the stratus. The stratus may take on more of the appearance of stratocumulus, which indicates a more unstable, turbulent marine layer. Surface visibilities normally improve following trough passage if the trough is accompanied by a change in the marine air mass. However, forecasters should be cautioned that fresher, relatively unpolluted marine air does not accompany every summer trough and is rarely accompanied during the stratus season by any easily distinguishable surface feature such as a frontal system. Thus, conventional forecast techniques based on analyses of synoptic-scale features often offer little help in forecasting day-to-day variations in stratus.

Corresponding reasoning can be applied when the effects of weak ridges upon stratus at Point Mugu are considered. With ridging aloft, there is an increase in subsidence resulting in increased stabilization, lower and stronger inversions, and hence lower and flatter stratus. During these periods of weak ridging, surface winds frequently have a southerly component and visibilities are commonly poor in variably polluted air. The smog particles not only restrict visibility but also serve as active condensation nuclei upon which stratus readily forms.

When the upper ridge is especially pronounced and the subsidence associated with it is so strong that the inversion is, in effect, driven into the ground. Point Mugu experiences warm, dry air and stratus-free skies. Of special interest here are those cases when the inversion slopes upward from clear, hot coastal plains to cool stratus-shrouded areas just offshore. Such conditions are infrequent during the stratus season, however, and are usually restricted to late spring and late summer when they do occur. During the winter, these situations occur frequently with the beginnings and endings of Santa Anas and are discussed under that section.

Higher Clouds: During the middle and late summer, at the height of the stratus season, southern California is subject to occasional invasions of moist, tropical, unstable air aloft which originates over southern Mexico and the ITCZ (Intertropical Convergence Zone). When local winds aloft are from the southeast (700-mb, 5-day mean charts show southerly flow over the southwest United States continuously from mid-July to mid-August) (reference 17), this moist air is transported over most southern sections of the state frequently resulting in thunderstorms

over mountains and deserts with middle and high clouds in coastal sections. Even at the coast, thunderstorms are observed at least once almost every summer. (See "Special Phenomena which May Severely Affect Range Operations.") Along the stratus-prone coastal strip, the tropical air aloft usually remains above the well-established marine layer so that stratus is often not markedly affected. During those infrequent occasions when cumulonimbus and thunderstorms reach coastal areas, stratus and the marine layer may be temporarily and locally destroyed in the vicinity of the showers. In some of these cases, cumulonimbus clouds may drift into the local area unnoticed due to a complete stratus overcast and the low clouds do not disappear until thunder and showers actually reach the station, thereby causing immediate dismay to both the forecaster and the observer.

When only high clouds are present above a stratus-filled marine layer, the most usual effect is to delay the normal daily dissipation of the low cloud by cutting down on the incoming solar radiation. This is often the reason for "unexplained" or "surprising" cases of summer stratus lasting all day. Conversely, if an extensive and unusually thick midcloud deck should cover both desert and coastal regions, the effect may be to decrease inland temperatures sufficiently to alter the coastal onshore flow and actually result in decreased stratus at Point Mugu. In addition, high moisture content aloft may prevent radiational cooling of the marine layer and thereby preclude stratus. Usually though, such extensive invasions of tropical air result in drastic modification of the lower layers as well, with cool marine stratus conditions being replaced by warmer, muggy, stratus-free conditions. Figure 4-11 shows hourly surface reports for a summer day with tropical cloudiness at the coast. The extremely hot temperatures in the desert reveal how complicated the cloudiness-temperature pattern can be in summer.

Effects of Subsynoptic (Mesoscale) Features

Local Variations of Inversion: In addition to the synoptic-scale variations just discussed, the inversion undergoes many local variations in height and intensity (reference 19), and each has some effect on local stratus conditions. Many of these local variations are directly related to the topography--mountains, coastlines, and islands--which variously alter the depth and flow of the marine layer with corresponding changes in the height and intensity of the inversion. These patterns of marine layer depth and inversion intensity show up as systematic variations which are therefore amenable to prediction, and also as more random fluctuations which can be analyzed only qualitatively and on a day-to-day basis (reference 19). A few of the systematic features of stratus and marine layer variability in space are as follows: (1) the thicker the marine layer, the thicker and more prevalent is the stratus (reference 19) (except during the approach of cold troughs aloft when turbulent mixing with drier air may preclude stratus

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SJC 1ØØØE25ØØ1Ø 73/61/3Ø1Ø/EØØØ
SNS E12ØØ25ØØ15 17Ø/65/55/311Ø/ØØ2
MRY E11ØØ25ØØ7 174/58/52/33Ø9/ØØ3/F BNK OFSHR
PRB 1ØØØE13ØØ25 15Ø/79/54/2ØØ6/999
SMX E1ØØØ16ØØ12RW-- 159/65/54/33Ø8/999/OCNL SPKL RB55
SBA 15ØØE25ØØ25 132/79/56/17Ø5/991
PMD 16ØØ25ØØ3Ø 1Ø8/1Ø3/44/231Ø/996
ONT -X25ØØ3HK Ø97/1Ø5/52/3211/985·ONT·6/21 UA 6/22 POM EV
LAX 15ØØ2Ø 121/73/58/2514/988/FEW ACCAS NW CU NE·LAX·6/18 SNA AE 6/56 NZJ AG AE 6/57
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LGB E14ØØ22ØØ15 125/82/55/2911/989
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SMO 18Ø-Ø15 2112/E99Ø
SNA 26ØØ8 81/71/2415G2Ø/E989
SAN O1Ø 125/75/62/291Ø/989
SCK E15ØØ25ØØ15+ 152/87/54/31Ø8/997/BINOVC
FAT E12ØØ25ØØ12 136/92/62/24Ø5/993
BFL 16ØØ8 13Ø/96/57/2611/993
SDB   AMOS                     / 91/ 41/3Ø1Ø/Ø22/ØØØ//-------------------------------
BIH 12ØØ15ØØE25ØØ7Ø 143/98/35/33Ø7/ØØ8 ACSL N QUAD DARK NW
TPH 2ØØ-ØØ4Ø 14Ø/95/32/1711/Ø19/FEW CU ALQDS ACSL W
DAG 12ØØ3ØØ-Ø3Ø Ø88/111/38/ØØØØ3------------------------------------------------
TRM 25Ø-Ø3Ø Ø51/121/34/Ø7Ø5/967/  FEW AC CU NW-N
BC
PSPTQRPUWT 117/3214/E973M
IPL O2Ø Ø58/12Ø/44/19Ø8/969
YUM
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Figure 4-11. Surface Hourly Reports for 1500 PDT, 25 June 1970, Showing Very Hot Temperatures Inland and Tropical Clouds at Coast.

entirely or convert it to a more convective cloud (reference 16); (2) the marine layer in summer appears to slope upward from about 800 feet deep in the west part of the Santa Barbara Channel to about 1,400 feet along the Santa Monica Bay coastline; (3) near the Santa Monica Mountains, the marine layer is about 300 feet shallower than it is 30 to 40 miles seaward (though this feature is not too discernible near Point Mugu); (4) a heaping-up of the marine layer and stratus normally occurs over and upwind of headlands; and (5) deformity of the marine layer and the inversion usually takes place over sun-heated topographic surfaces (reference 19). Superimposed on these average trends are numerous random and transient humps and hollows within the marine layer with typical distances between "highs" and "lows" of about 30 or 40 miles, but with considerable variability noted.

From a diurnal point of view, the inversion is subject to regular oscillations in height due to vertical shrinking and stretching of the marine layer caused by the land- sea-breeze circulation (reference 7). Added to this are the effects of solar insolation resulting in convective heating of the marine layer inland during the day. Over the near-shore waters, these effects result in the inversion being lowest in the afternoon (at the peak of the sea breeze) and highest in the morning (at the peak of the land breeze). This general pattern is not completely uniform everywhere along the coast; the maximum decrease in inversion height occurs during the afternoon just off the Ventura-Oxnard area and also just west of the Los Angeles coastal plain. Relative minimum of falls occur at Point Mugu and near the Palos Verdes Peninsula. These variations are attributable to the shape of the coastline; concave coastlines result in sharper inversion height falls offshore, and convex coastlines (like Point Mugu's) result in smaller daily inversion height falls (reference 19). In general, the inversion offshore is also observed to increase in stability during the afternoon hours.

At inland locations, an opposite pattern of inversion height change appears. Peak inversion heights occur in afternoon and lowest heights occur in the morning. Unlike offshore inversions, the inversion inland is observed to decrease in stability during the afternoon due to the convective effects of normal daytime warming (reference 20). Height changes of a few hundred feet are typical of inversion fluctuations both inland and offshore.

In addition to these marine layer and inversion variations due to the basic differences between land and sea and the orientation of coastlines, orographic (mountain) effects upon inversion, height, and intensity may also be considerable. For instance, at the coast in the vicinity of the Santa Monica Mountains, there is an increase in stability of the marine layer and decrease in stability of the inversion as compared with conditions well offshore. In other words, next to the coastal mountains, there is less contrast between the marine layer and the inversion. This is

attributable to heating of the top of the marine layer and bottom of the inversion by contact with sun-warmed slopes of the hills (reference 19) and is further evidence of the rapid and substantial influences that topography exerts on the lower atmosphere as it flows landward from the Pacific. It is possible that topography may also be cited as a cause of still another interesting feature often observed during a PMR-sponsored study of the offshore inversion when an instrumented light aircraft was used (reference 19)--the noncoincidence of the top of the marine layer with the base of the inversion. On several days, mixing ratios (absolute humidities) within the inversion were found to be equal to those within the marine layer. A possible cause of this effect is topography induced subsidence which warms the top of the moist marine layer, and an important consequence is the possible need for a new definition of the term "marine layer."

The Santa Ynez Mountains to the north (together with the change in coastline orientation near Point Conception) result in further large-scale deformities of the marine layer, and show up as waves within the marine layer which are larger than the Channel Islands. These waves frequently lead to eddy formation to the lee of Point Arguello and Point Conception although they may extend southward and eastward for various distances, depending on their size and the overall synoptic situation. The particular name "Catalina Eddy" has been assigned to that class of eddies which are centered offshore southern California and close to the island of that name. The importance and development of this eddy will be discussed later in this handbook.

Whether associated with a particular eddy or not, the Channel Islands themselves cause a perceptible warping of the marine layer in their immediate vicinity because they act as obstacles to the otherwise near-uniform marine layer flow. The inversion is frequently lower and stronger over the normal downwind part of San Nicolas Island as compared with inversions observed at the upwind site. This is a result of forced subsidence, and frequently leads to a hole in the stratus over the southeast end of the island. Fortunately, this is where the island's runway is located and the clearer region is an aid to aircraft and pilots in an otherwise hostile flying environment. A clue to the effects of San Nicolas Island upon prevailing stratus in the area is a frequently noted hourly surface report, "F BNK SRNDG ISLAND" (fog bank surrounding island).

When looked at on a finer scale, local stratus cover often exhibits various patterns, structures, and voids which are dependent upon such factors as marine layer depth, stability of the atmosphere, and wind flow. One of the most common stratus features observed are longitudinal "rolls." These are always parallel to the wind which makes them a useful means of estimating wind directions over large areas of the Sea Test Range from an aircraft and they are attributable to convection within the marine layer

(reference 19). These should not be confused with the "anomalous cloud lines" seen extending for hundreds of miles within stratus areas (as shown in figure 4-1) west of California. These lines are attributable to the release of large numbers of nuclei from ocean-going vessels (reference 21). In addition to the rolls and lines, there are frequently-observed gravity waves which are normal to the flow. Some of the steep-sloping gravity waves may break just like surf in the ocean and become cloudy regions of marked turbulence. On a still larger scale, when the marine layer is fairly stable, gravity waves can result in crescent-shaped holes in the stratus cover immediately downwind from islands. These features commonly appear on local satellite pictures near the Channel Islands and Guadalupe Island off the Baja California coast as these islands poke up into the moving marine layer (figures 4-12 and 4-13). From their appearance, estimates of the stability of the marine layer can therefore be inferred for wide areas. When there is an exceptionally strong inversion, island obstacles may produce "bow waves" similar to those produced at sea by a moving ship. And finally, when the marine layer is thick and there is a solid stratus deck, island locations beneath the cloud cover may be revealed to a pilot by a thickening and humping up of the cloud over the island. Overall, deep marine layers tend to have simpler stratus patterns than shallow marine layers (reference 19).

Catalina Eddy: The Catalina Eddy is the popular name applied to a group of subsynoptic-scale cyclonic circulations within the marine layer offshore of southern California, often centered near the island bearing that name. Due to frequent speculation about its origin as well as a wide spectrum of observed sizes, intensities and locations of its center, the Catalina Eddy has had wide verbal acceptability among southern California meteorologists but only limited references have been made in the literature until recently (references 14, and 22 through 27). When well-defined, the eddy has important effects on ambient stratus conditions over the coastal strip from Baja California to Point Mugu and westward to at least Santa Barbara. The eddy has most commonly been attributed to orographic effects of the coastal mountains north of Santa Barbara which cause the normal northwest flow paralleling the California coast to turn cyclonically in the lee of the east-west mountain range and downwind from Point Conception (references 14, 25, and 26). Very recently it has been shown that the approach of upper-air synoptic-scale troughs toward the southern California coast is also essential to Catalina Eddy development. Thus while it appears that Catalina Eddies are subsynoptic in size, they are caused by and are integrally related to the large-scale synoptic flow. Such an idea was briefly implied in a U.S. Forest Service study of 1959 (reference 28) and later by Kauper, et al (reference 24).

(a) ESSA 6 APT, 27 May 1968, 1728Z. Photo shows Point Mugu, coastal southern California, and adjacent waters free from stratus following offshore flow at the surface. Stratus is present along Baja California coast.

(b) ESSA 2 APT, 28 May 1968, 1522Z. Photo shows early stages of Catalina Eddy. Note cyclonic spiral of stratus.

Figure 4-12. Development of Catalina Eddy, 27 - 29 May 1968 (Reference 26).

(c) ESSA 6 APT, 28 May 1968, 1821Z. Photo shows progression of stratus in cyclonic spiral of eddy. Note the isolation of clear, dry air.

(d) ESSA 6 APT, 29 May 1968, 1717Z. Photo shows the complete envelopment of Point Mugu, coastal waters, and the region to the south by thick stratus. The clear, dry area has now been filled up by clouds from the dying eddy circulation.

Figure 4-12. Concluded.

Figure 4-13. Train of Waves in Marine Layer Downwind From Guadalupe Island. ITOS 1 IR, 3 June 1970, 2233 - 2254Z.

Since the eddy itself is subsynoptic, it is a feature that is not easily detectable on conventional surface analyses due to the paucity of observations over the offshore areas and the fact that the few island winds and pressures that are available are often not representative of conditions over the open water (reference 29). One of the most widely used parameters to determine the existence of a Catalina Eddy is the occurrence of southerly surface winds at San Diego (references 22, 27, and 30). This direction is in sharp contrast to the normally observed northwest winds when no eddies are present. At Point Mugu, moderate or strong southeast winds during the stratus season are an almost certain indication of the presence of an eddy. Southeast winds are also observed elsewhere along the coast.

The great significance of Catalina Eddies is the substantial modification of the marine layer and stratus which result from the circulation. The principle effect seems to be a deepening of the marine layer along the coastal strip with a corresponding rise in the height of the inversion and in the height, thickness, inland extent, and duration of the stratus. It is frequently responsible for rapid advection of stratus to previously clear regions and for markedly improved ceilings over coastal regions and low ceilings and poor visibilities over higher inland terrain. In addition, heavy pollution over the Los Angeles Basin may become advected along the coast and out to sea as it becomes mixed vertically through the deepening marine layer.

The development of a classic example of a Catalina Eddy on 27 through 29 May 1968 is shown by a series of APT pictures recorded at the PMR Weather Center (reference 26). An ESSA 6 picture on 27 May (figure 3-12(a)) shows Point Mugu, coastal southern California, and adjacent waters free of clouds following a day with general offshore flow at the surface. Nearly all coastal stratus was restricted to Baja California. The coastline and interior landmarks such as mountains and the Salton Sea appear with remarkable clarity when normal inland penetration of hazy marine air is prevented by the offshore flow. Snow cover on the Sierra Nevada provides a fixed reference in this and succeeding pictures.

Even while clear conditions prevailed, the first evidence of eddy formation began to appear during the early morning hours of 27 May with cessation of much of the offshore flow and the start of sporadic bursts of southeast winds at some coastal locations. Later in the day, more continuous southerly winds appeared at San Diego and Los Angeles Basin stations while the usually northwest winds at San Nicolas Island (elevation 571 feet) turned to northeast. The first major effects of the eddy were observed near midnight when brisk southeast winds were recorded at Point Mugu and fog and low stratus rolled over much of the coast.

The invasion by stratus is shown vividly in the ESSA 2 picture taken the following morning (figure 3-12(b)). The prominent feature is a spiral formation whose outer boundary envelops the coastal area from the Mexican border to Point Conception. The inner boundary of this spiral between the cloudy air and the clear (presumably drier) air is sharply delineated. Depth of the cloud deck is generally shallow as several of the Channel Islands, whose maximum elevations range from 635 to 2,471 feet, can be seen penetrating the stratus cover. To judge from the apparent progression of this spiral cloud pattern in the subsequent 3 hours (figure 3-12(c)), the circulation is cyclonic in a sense. In this latter picture, the pocket of clear air has been cut off or isolated and is becoming mixed with cloudy air. Note also the crescent-shaped holes in the stratus downwind from the islands as discussed in the previous section.

An ESSA 6 picture taken the next morning (figure 3-12(d)) reveals that stratus has engulfed the entire southern California coast and offshore waters, and eliminated any trace of the pocket of clear air noticeable the previous day. The marine layer appears to have deepened considerably as only the highest portions of the islands are now visible through the cloud deck. Further evidence of a higher stratus deck is the substantially higher ceilings reported at coastal stations. Point Mugu ceilings were 1,500 feet on 29 May as compared with zero-zero conditions at the time of stratus onset on 28 May. Even though pictorial evidence of continued cyclonic eddy circulation

is not apparent, the deep marine layer and high stratus remain as testimony to the Catalina Eddy and its effects upon Point Mugu and coastal southern California weather.

Although the effects of the Catalina Eddy seem well fixed in the minds of the local forecasters, the predictability of this feature is another matter. During the stratus season, a strengthened northwesterly surface flow at Point Conception and the approach of an eastward-moving upper air low or trough may be considered the most likely forerunners. During the beginning and ending of the warm season, approaching troughs tend to be stronger and colder so that some of the strongest eddies appear to form during these periods. In addition, the normal northwest flow and onshore pressure gradient at the surface reach their peak values along the California coast during the spring months, March through May (reference 31). In a recent study by Arthur Eichelberger of the National Weather Service Forecast Office, Los Angeles (reference 27), it was shown that a surface pressure gradient of 5 to 10 mb from 35°N 125°W to Los Angeles (or Point Mugu) and positive vorticity advection resulting in vorticity values of 7 to 10 units (10^{-5} sec^{-1}) at Los Angeles will generate Catalina Eddies. The normal sea level pressure gradient from 35°N 125°W to Los Angeles is 6 mb in July so that the northerly surface winds along the California coast are nearly always strong enough in spring and summer to result in Catalina Eddies, provided that the necessary positive vorticity advection is also present. For these purposes, it was found that the primitive equation prognostic vorticity charts as transmitted over the national facsimile network are highly useful in forecasting the development of Catalina Eddies.

As for specific guidelines which the local forecaster can apply, Eichelberger states:

> Strongest eddy situations are those in which a decelerating frontal trough moves into southwestern United States, accompanied by vorticity maxima of 14 units or more in southern Nevada and 12 units at Los Angeles. Under these conditions, and given the necessary strong northerly winds along the coast, explosive deepening of the marine layer can be anticipated. However, if the vorticity reaches 13 units or more at Los Angeles and higher values prevail inland, the eddy will be swept away in a strong general onshore flow. If a series of shortwave troughs with half-wave lengths of 600 miles or less are passing through the area, the eddy, if any, will be poorly organized and short-lived: and there will be insufficient time for any significant changes in southern California coastal weather. Once formed, an eddy will persist until either frontal passage occurs, a vorticity maximum passes, the marine layer

deepens to 5,000 feet and spills over the coastal mountain range, or vorticity values over coastal waters increase to 13 units or more and a general onshore flow ensues.

Pseudo-Catalina Eddies: Isobaric analyses over southern California frequently show a small closed surface low near San Nicolas and Catalina Islands (reference 29). On the basis of lower pressures at the two island stations than at coastal mainland stations, together with northwest winds at San Nicolas and west-southwest winds at Catalina, such an analysis may suggest an incipient Catalina Eddy. Formerly, a sea level pressure at San Nicolas Island more than 1-mb lower than at Los Angeles was thought to be a good indicator of eddy formation. It is suspected, however, that many times when this or similar pressure differences are observed, a true Catalina Eddy does not actually exist.

The reasons for this conclusion are twofold: (1) because both San Nicolas and Catalina Island weather stations are located considerably higher than sea level, standard procedures are used to reduce station pressures to sea level. However, if there is a low strong inversion--which there frequently is--with base below the altitude of the island weather station, the sea level pressure computed for the island station will be lower than the actual sea-level pressure measured at a beach weather station; and (2) there is a probable topographic bias for Catalina surface winds to be reported from west-southwest.

These two factors lend to a built-in tendency for pseudo-Catalina Eddies on weather charts. Further details may be found in appendix C.

It is hoped that the Geophysics Division's NAFI, NOMAD, and ODCS* oceanographic buoys, now planned for installation in the inner and outer Sea Test Range areas, will permit a much more realistic and accurate analysis of true surface pressure patterns offshore coastal southern California. When they become operational, data will be received automatically by teletype in the PMR Weather Center.

Pollution: Large masses of pollution, consisting of both old and fresh smog and particulates, commonly extend out from the Los Angeles Basin and Oxnard Plain to offshore areas. The amount and extent of such offshore accumulations are highly dependent upon synoptic and local weather patterns, inversion conditions, the land or sea breeze regime and the time of day. During late morning and early afternoon, Point Mugu experiences the greatest influx of such offshore accumulations with the frequently observed veering of the wind to southeast, south, and finally southwest or west. Most of the important effects of smog upon Point Mugu weather are discussed

*NAFI is Naval Avionics Facility Indianapolis; NOMAD is Navy Ocean and Meteorological Automatic Device; and ODCS is Ocean Data Collection System.

toward the end of this handbook under "Special Phenomena Which May Severly Affect Range Operations: Smog." However, it is pertinent to point out here that extensive smog layers within the marine layer are most probably an aid to stratus formation and an inhibitor of stratus termination. Not a great deal is known about the exact role or importance of smog in stratus conditions except for the apparent activity of particulates as condensation nuclei which, as stated previously, was inferred in studies conducted by Neiburger (reference 7). The problems of visibility restriction due to pollution and natural aerosols and their effects on coastal southern California weather is currently being studied, including the validity of such often-referred-to phenomena as "marine haze." For the present, it may be assumed by the forecaster that an influx of smog into the local area will both increase the likelihood of stratus (even during midday) if none previously exists, as well as inhibit stratus dissipation if it is already present.

Termination of Stratus and Fog

Termination Defined

The disappearance of stratus such as typically occurs around midday over much of coastal southern California during the stratus season, is loosely referred to as "termination." The time, both observed and forecast, of stratus termination at Point Mugu is of great significance to range planners and operations people. Based on operational requirements, it may be defined as the time when either overcast or broken sky cover changes to either scattered or clear conditions; that is, when the ceiling condition ends.

Because of varying proximities of portions of Point Mugu to the cool ocean over which stratus lies, the amount of stratus and time of its termination varies widely over the Station. For instance, termination usually occurs much earlier over the housing area than it does near the beach and seaward end of runway 03-21, if it occurs at the latter places at all. Since it is practical to have only one description of weather conditions over an air station at a single time, the official observations taken at the PMR Weather Center must form the basis for describing when Point Mugu has or does not have a low-stratus ceiling. Nevertheless, it should be kept in mind that wide variations in local stratus cover and times of termination are frequently observed.

Processes By Which Stratus Terminates

There are two processes which cause stratus to terminate: dissipation or "burnoff," as it is sometimes called, and advection of clouds away from the station. These two mechanisms are analagous to the two cited for stratus onset: formation overhead and advection of clouds towards the station. Also as in the case of stratus onset, the two processes of termination frequently occur together making it difficult to establish the relative importance of one over the other.

Dissipation: The process of dissipation, or burn-off, is simply one of evaporation. As solar heating progresses slowly during the day, the amount of mixing of warmer, relatively drier air from outside the cloud with the saturated air with the cloud increases to the point where parcels of cloudy air are warmed above the condensation temperature. In addition, some heating of cloudy parcels are accomplished directly from the sun's rays. Although dissipation of stratus probably occurs simultaneously from its base, top, and edges, it is likely that the dissipation is most rapid at the edges of stratus decks over land where the solar heating effects and mixing are most intense. Since a temperature inversion nearly always overlays the stratus, mixing and dissipation of stratus are probably slowest from the top due to the resulting stable temperature stratification.

In addition to heating, a lower relative humidity with resulting dissipation of stratus can also occur due to an overall decrease in air mass moisture from offshore flow such as strong land breezes or synoptic scale flows, or from drier air brought into the circulations of polar troughs in the westerlies.

Advection of Stratus Away From Point Mugu: Advection of stratus away from the station is typically accompanied by a flow of drier air into the area which seems to "push" the stratus out to sea. The leading edge of a Santa Ana flow is the best example of such an occurrence, although dissipation undoubtedly also plays a part. Occasionally, a moderately strong land breeze around sunrise will also advect stratus seaward after the station has had a low overcast most of the night. Sometimes, the advection of stratus away from the station may proceed inland instead of the usual way toward the ocean. This can occur when a fresh, clean westerly sea breeze begins to blow into an area of pre-existing polluted stratus cover. It has also occurred in summer due to the outflow from a thunderstorm and cumulonimbus clouds located nearby over the water.

As mentioned at the start of this discussion, both dissipation and advection usually occur together, sometimes in the same sense (for termination of stratus) and sometimes in opposite sense. A frequently observed example which illustrates the latter is the oscillating position of a wall of stratus over the base resulting from advection of a seaward cloud mass towards the station and dissipation of its leading edge as it moves over the warmer land.

Mesoscale and Synoptic-Scale Features That Affect Stratus Termination

Mesoscale Features:

A. Diurnal Sea-Land-Breeze Regime. The diurnal pattern of the solar heating cycle and the associated daytime sea breeze and nighttime land breeze is the most important feature which affects stratus termination during the warmer months when synoptic features are characteristically weak or

nonexistent. There are three separate effects, each one important for termination of stratus at Point Mugu.

B. Heating. The heating of the air under and surrounding a stratus cover by the solar heating of the land (with resultant mixing), plus direct heating of the cloud itself, lead to the familiar dissipation of stratus around midday. These processes lower the relative humidity, the air becomes effectively drier, and evaporation of clouds occurs. These processes are counteracted slightly by radiational cooling from the cloud top.

C. Winds. The afternoon sea breeze tends to counteract the termination of stratus both by bringing in cooler marine air with high relative humidity and through actual advection of pre-existing ocean stratus. During the morning hours, the onset of a moderately strong land breeze may lead to termination of stratus.

D. Inversion. A[illegible]scussed previously under "Factors That Modify Stratus and Fog," the land-sea-breeze regime sets up fields of convergence and divergence which, in turn, lead to vertical stretching and shrinking of the marine layer (reference 7). This results in a general lowering of the inversion in coastal and offshore areas during afternoon at the same time that a rising and weakening of the inversion takes place over inland heated areas (reference 20). If the lowering coastal inversion sinks below the lifting condensation level, stratus termination will take place because of dissipation. This probably explains how afternoons can be so clear, even at considerable distances offshore during strong sea breezes.

Air Pollution: If the marine layer over Point Mugu is polluted from local or Los Angeles Basin sources, as is frequently the case (references 32 through 34), stratus may persist at relatively lower humidities than if the marine air were unpolluted. Thus, on smoggy days stratus termination is likely to be slower than on days with clean marine air. The reason for this is the apparently active role that pollutants play as condensation nuclei (reference 7), as was discussed in preceding sections on stratus modification. Since low-level southeasterly and southerly flow is the mechanism most responsible for bringing Los Angeles Basin-polluted marine air into the Point Mugu area, it follows that stratus termination is less likely here on days with low level southeast winds than it is on days with fresh westerly sea breezes. Recent studies have shown, however, that smoggy days can occur even with west winds (reference 34). On such days, the pollution may be from local sources or else the west wind may be a local flow within an overall smoggy mass of air which originated in Los Angeles and/or the Oxnard Plain. Some photographic examples and more detailed description of the effects of air pollution and smog in the Point Mugu area are given in part IV.

Catalina Eddy: Catalina Eddies, as described earlier under "Factors That Modify Stratus and Fog, Effects of Subsynoptic Features," can profoundly alter the pattern of stratus over southern California, and often quite rapidly as in the case of the previously described example of 28 May 1968 (figures 4-12(a) through (d)). Eddies will usually have an inhibiting effect on stratus termination; i.e., they tend to prolong, extend, and thicken the low cloud and therefore counteract the normal daytime tendency for dissipation. As was pointed out earlier, eddies vary considerably in size, intensity, and duration so that their effects on stratus are predictable only in general terms. Briefly, the effects of eddies on stratus termination may be summarized as advection of stratus and pollution into the local area with southeast flow and the establishment of a deeper, more unstable marine layer capped by a strong inversion --all of which tend to delay termination of stratus at Point Mugu. If, on Catalina Eddy days, the wind should subside and veer to southwest or west in the afternoon, stratus will often terminate. The veering of the wind in such cases represents at least a temporary breakdown of the eddy.

Synoptic-Scale Features

Troughs and Fronts: The effects of troughs and fronts on termination of stratus depend on the degree of activity of these features. Ahead of relatively weak troughs and fronts which commonly occur during the stratus season, the slightly convergent, deeper marine layer will likely delay the daytime tendency for stratus to dissipate. This is because there is more turbulent mixing to cause clouds, there is a deeper layer of air requiring additional heating to evaporate the clouds, and because the stratus deck is likely to be thicker initially. Following passage of a weak front or trough in the westerlies, low-level subsidence, slightly drier air, and relative lack of pollution tend to favor an increase in dissipation of stratus, and cause it to terminate earlier.

When fronts and upper troughs are more active, as they typically are during the late fall, winter, and early spring, the inversion is markedly weakened and lifted ahead of the front while the marine layer experiences a much greater degree of convective overturning, instability, and advection of drier air. Active fronts thus are especially effective in terminating stratus both before and after their passage.

A feature sometimes seen on local APT satellite pictures is a clear band, perhaps 50 to 100 miles wide, in the stratus area directly in front of and parallel to a band of frontal clouds. The feature has been observed by Dvorak and appears to be related to the synoptic-scale flow (reference 35). An example is shown in figure 4-14. Two hypotheses with nearly opposite reasoning have been applied to explain this feature. One suggests that subsidence downstream from the front evaporates the clouds. The other idea requires that upward motion prevails

Figure 4-14. Clear Band in Stratus Ahead of Frontal Clouds.

there on a scale large enough to preclude stratus formation by wholesale mixing, but not large enough for formation of convective and midlevel frontal clouds. A similar clear region surrounding tropical storms (see "Transient Weather Regimes and Features," and figure 10-6) seems to be explainable by the subsidence hypothesis, but upward motion seems to be more likely ahead of fronts. Whatever the cause, if this feature is observed moving toward Point Mugu, forecasters should be aware of the possibility of stratus termination ahead of the front.

Ridging Aloft and Offshore Flow: As was the case with troughs and fronts, the terminating effects upon stratus by ridging aloft and offshore flow are also dependent on the strength or activity of the synoptic features. During most of the stratus season, when the strong westerlies aloft are located well to the north, ridging effects are subtle and are rarely accompanied by offshore flow at the surface. The increase in subsidence does, however, serve to lower and strengthen the inversion. Thus, stratus is typically thinner and, with less marine air volume to be heated above the condensation point, termination of stratus occurs earlier because of enhanced dissipation. Should the inversion be lowered beneath the lifting condensation level, stratus can be precluded altogether.

During the early or late days of the stratus season but particularly during the other colder months of the year, high pressure sometimes builds over the Great Basin area at the same time that ridging aloft occurs over the western states or coastal regions. The surface buildup of pressure usually reorients the low-level pressure gradient so that airflow is more offshore, and the result is that stratus termination due to dissipation occurs at a very

rapid rate and early in the day. Not only is dissipation enhanced by the thinness of the cloud and the shallowness of the marine layer to be heated by the sun, but also by the increased dryness of the air by virtue of its source in the continental interior. The heating of the air due to adiabatic compression as the air subsides and laterally descends towards sea level creates a very warm inversion which is also associated with early termination of stratus.

When the offshore flow extends right down to the surface, Point Mugu experiences the well-known Santa Ana and any pre-existing stratus is immediately terminated by both dissipation and advection at the advancing edge of the dry, subsiding, turbulent, inversion-destroying air mass. Just how far out to sea the stratus-terminating effects of such offshore flows extends is generally unknown. Some estimates of seaward effects can perhaps be inferred from figure 4-15 which shows two interesting features. The first is the large clear "hole," within a large mass of offshore stratus and low clouds, extending out about 500 miles to the south and southwest of the southern California coastline, which may represent the area over which the offshore flow dissipates stratus, whether due to drier air or lowered inversion or both. No stratus was observed at Point Mugu before the start of the offshore flow so this example is not identical to the problem of termination of stratus. The other interesting feature in the picture (figure 4-15) is the dark region protruding out over the offshore area from Point Mugu and the Malibu coastline, which is readily discernible from the very dark coastline and the brightly lit sunglint region within which it is embedded, and is presumably due to the offshore flow at the surface (the "Santa Ana") disturbing the waters and changing their reflectivity. Thus it seems that, in this case, the actual Santa Ana flow at the surface extended in a narrow zone only about 100 miles to sea whereas the overall effect upon seaward stratus by the synoptic flow was considerably larger.

Figure 4-16 shows the effect on stratus of another large-scale offshore flow. In this case, high-pressure, drier, continental air was pouring off the British Columbian coast of Canada for a distance of hundreds of miles. The hook-shaped feature nearer the coast may be associated with the center of a low.

It should be noted that as in most meteorological considerations, there are opposing possibilities which occur with a frequency great enough to justify their mentioning as an exception to the rule. One is when a moderate or strong offshore flow over Point Conception breaks down into an offshore eddy under the influence of the east-west Santa Ynez mountains. If this happens, the effects upon stratus termination will be as previously discussed for all Catalina Eddy situations.

Figure 4-15 Seaward Extent of Offshore Flow and Santa Ana, ESSA 6 APT, 9 April 1968, 1829Z.

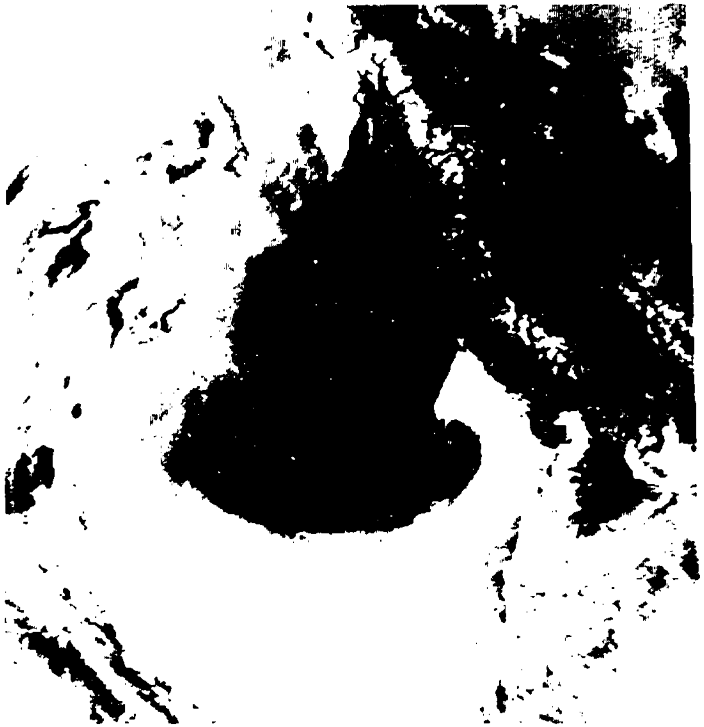


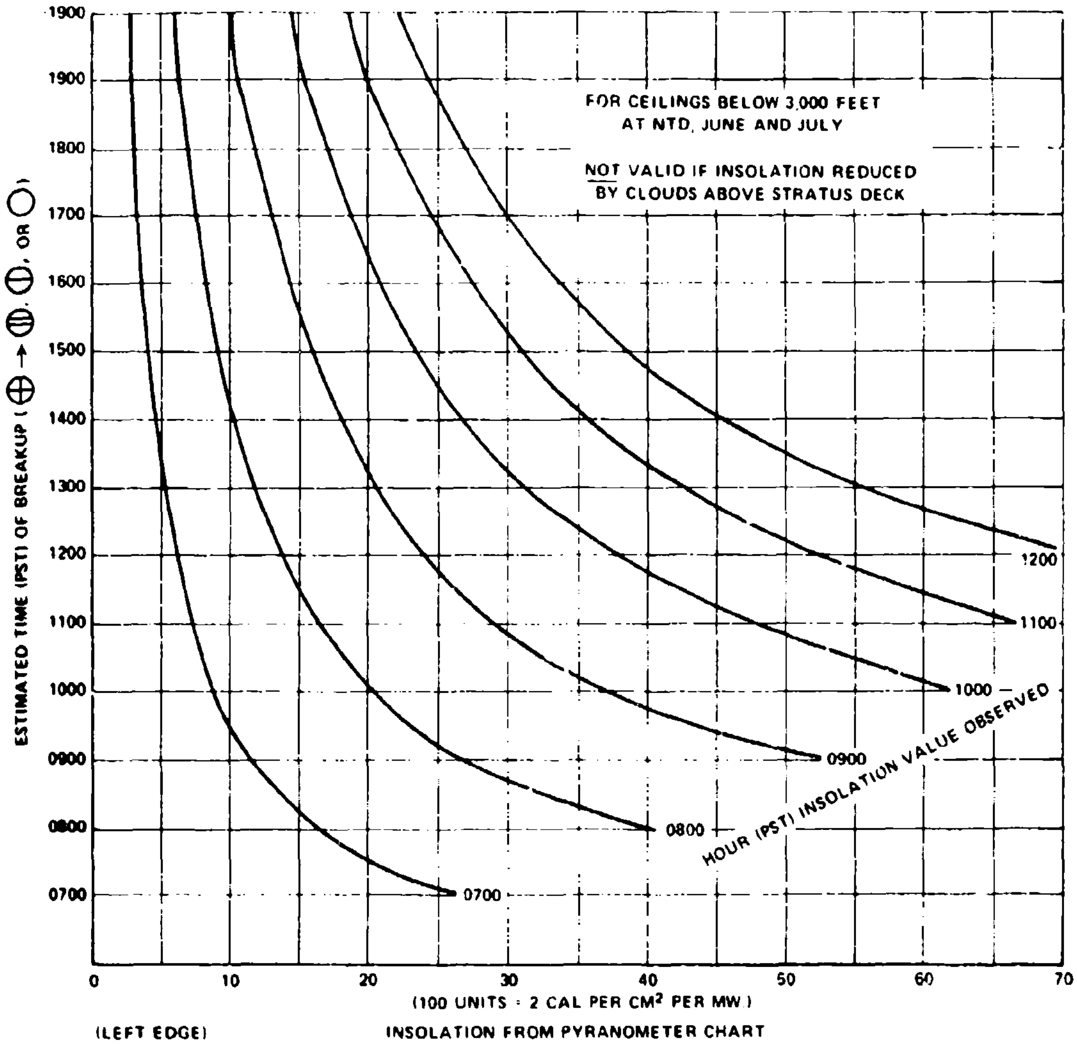
Figure 4-16 Clearing in Stratus Due to Large Scale Offshore Flow, Nimbus 3 APT, 10 June 1969, 1917 - 1935Z.

Tropical Air: An invasion by tropical air from Mexico or the Gulf of Mexico may have an effect on the termination of stratus at Point Mugu. If the flow of tropical air aloft is appreciable, midclouds characteristically appear and a widespread decrease in solar insolation may result in weakened onshore flow and a reduction in the extent of stratus. High moisture content aloft may by itself prevent cooling of the marine layer by radiation resulting in less stratus. If the tropical flow is weak and only high clouds are present above the stratus, a later termination of stratus may result from a delay in diurnal dissipation effects. The precise tie-in between the surface and upper airflow under such conditions is very speculative and so must be any considerations as to their effects on stratus.

Occasionally, warm tropical air from the south may extend downward to near the surface. When this happens, the overall synoptic features causing this to occur will also usually result in a very low, warm inversion (or no inversion at all if it does touch the surface) and dissipation of stratus may be widespread.

In general, when southeast winds are observed or are forecast to occur above 10,000 feet at Point Mugu during the stratus season, forecasters should be aware of the possibility of dense midceilings and stratus termination. On the other hand, if only high clouds are anticipated, stratus prolongation is possible.

Tabulations of times of stratus termination (or "breakup") and observed insolation readings from the Geophysics Division pyranometer for the months of June and July of 1967 and 1968 formed the basis for development of an easy-to-use objective aid for forecasting stratus termination by use of observed insolation readings. The forecasting rules are displayed as a series of curves in figure 4-17 and are valid only for ceilings below 3,000 feet and for cases where there are no higher clouds present above the stratus. The former restriction is quite reasonable since typical stratus occurs below 3,000 feet. The second restriction implies that the objective aid may not be used during those infrequent periods of tropical air influx aloft by southeast winds. Since an observer may not know, in the absence of aircraft reports, whether there are any higher clouds above the stratus or not, he should consult the latest sounding for reports of southeast winds and any appreciable humidities (50% or more) at nonstratus levels. Hourly reports from nearby coastal and desert stations may also prove useful in determining whether higher clouds are also present. The curves in figure 4-17 are for the months of June and July only, the months during the stratus season when higher clouds of tropical or polar origin are least likely and, therefore, for which the forecast rules are most likely to apply.



1. Read insolation value from pyranometer chart (in chart scale units- -zero at left edge).
2. On curved line corresponding to hour of observation (PST), locate point aligned vertically with observed insolation value.
3. Read estimated time of start of stratus breakup.

Figure 4-17. Time of Stratus Breakup Based on Solar Insolation Values. (Curves prepared by R. A. Helvey.)

FIGURE 4-17

Stratus Termination at San Nicolas Island

Large-scale synoptic features seem to affect stratus the same at both Point Mugu and San Nicolas Island. On any given day, however, there are notable differences, many of which may be due to local variations of wind, turbulent mixing, and inversion conditions. Apparently, the rocky island is subject to the same diurnal evaporation or dissipation of clouds by solar heating as is Point Mugu but with more topographic effect and less sea breeze effect. Sometimes a Catalina Eddy may result in nearly stratus-free conditions at San Nicolas Island under light northerly flow and produce a thick marine layer with higher, longer-lasting stratus at Point Mugu under southeasterly flow. Even on San Nicolas Island there are sometimes widespread differences in prevalence of stratus over different areas of the island as was pointed out under "Modification of Stratus." It seems that stratus termination occurs earlier and more often over and downwind of the island than it does on the windward side, but it appears that stratus termination at San Nicolas Island occurs far later and less consistently, if at all, than it does at Point Mugu.

THUMB RULES AND FORECASTING AIDS ON STRATUS AND FOG

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
STRATUS ONSET				
Stratus will form if the inversion is strong and the offshore high and inland low combine to form isobars parallel to the coast between Point Conception and San Diego.	✓			4-11
Stratus is likely if heavy smog and haze are present.	✓			4-7, -41
Catalina Eddies result in thick, persistent stratus at Point Mugu.	✓			4-37
Catalina Eddies may be induced by synoptic-size features, i.e., troughs or lows aloft.	✓			4-34
Beware of pseudo-Catalina Eddies. (a) Sea level pressure at NSI will be 1/3 mb low for every 5°C of inversion below the station. (b) Catalina Island winds are frequently WSW due to topographic effects.		✓		*
Warmer ocean surfaces are more conducive to stratus formation.			✓	4-12
Colder ocean surfaces are more conducive to stratus formation.			✓	4-12
ASSOCIATED WEATHER				
During the stratus season, it is clear about 1/3 of the time, overcast about 1/3 of the time and transitional from one to the other about 1/3 of the time.	✓			4-15
Low visibility beneath stratus is a general characteristic of the stratus season due to fog, haze, and pollutants.	✓			4-16
Visibility under stratus improves following frontal passage.		✓		4-16
The higher the inversion, the higher and thicker the stratus.	✓			4-16, -18
The base of the inversion is a good approximation to the top of the stratus.	✓			4-16
Drizzle falls from thick stratus.			✓	4-16, -18
Stratus persists longer and is higher during a Catalina Eddy, as long as southeast or southerly winds persist.	✓			4-44
Stratus heights at NTD and NSI may differ by a thousand feet.		✓		4-20, -32
Early in stratus season, average ceilings tend to be higher and longer lasting than in mid or late summer.	✓			4-14

*See appendix C.

THUMB RULES AND FORECASTING AIDS ON STRATUS AND FOG (Concluded)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
As the peak of the stratus season is approached, mornings at Point Mugu get cloudier whereas afternoons get clearer.	✓			4-14, -24
Worst flying weather reaches maximum frequencies earlier in the morning and later in the year as the stratus season progresses.	✓			4-16, -17
The greatest cloudiness and the least cloudiness of the "average" year occur only a few hours apart in August.	✓			4-14, -25
Stratus often covers the coast of the Oxnard Plain during the stratus season while the coast to the southeast of Mugu rock remains clear.		✓		4-25, -32 Ch. 1
STRATUS TERMINATION				
Stratus typically terminates through evaporation or dissipation near midday.	✓			4-23, -24, -42
Stratus termination is characterized by oscillations of more and less cloud cover.			✓	4-42
Stratus terminates later during Catalina Eddies.		✓		4-44
Stratus terminates earlier under west winds than southerly winds (includes cases where wind veers in afternoon of Catalina Eddy day).	✓			4-44
Stratus usually terminates following frontal passages.		✓		4-44
Strong troughs terminate stratus both ahead and behind the trough.	✓			4-44
Weak summer troughs cause stratus to terminate a little later in the day ahead of trough (due to higher cloud, etc.) and a little earlier in the day following the trough passage.	✓			4-44
High clouds prolong stratus; midclouds are associated with early daytime termination.			✓	4-48
Stratus terminates immediately with onset of Santa Ana due to both dissipation and advection.	✓			4-46
During Santa Anas, stratus termination occurs much farther to seaward than does the actual off-shore surface wind.		✓		4-46

PART III. TRANSIENT WEATHER REGIMES AND FEATURES

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CHAPTER 5

SANTA ANA DEFINED

The Glossary of Meteorology (reference 6) defines a Santa Ana as "a hot, dry, foehn-like desert wind, generally from the northeast or east, especially in the pass and river valley of Santa Ana, California, where it is further modified as a mountain-gap wind . . ." This description and nomenclature pertains not only to the Santa Ana canyon but to all of the southern California region (reference 32) including Point Mugu and reveals the three dominant features of the Santa Ana as observed by the average person: wind, dryness, and warmth. Nevertheless, there are enough variations in synoptic patterns and weather observed to frequently make local meteorologists disagree as to whether a specific episode of northeasterlies is a typical, non-typical, or no Santa Ana at all.

Geophysics Division personnel have reduced the many observations of Santa Anas recorded over the years into a climatological picture of Santa Ana characteristics at Point Mugu. For this study, certain arbitrary criteria were chosen to objectively distinguish real Santa Anas from other synoptic events. In so doing, some borderline cases were unavoidably omitted but these special cases will be discussed separately later on. The statistical pictures are derived by use of the most common characteristics of Santa Anas at Point Mugu and are used in the following sections to provide quantitative support to our qualitative descriptions of the Santa Ana. The entire set of summaries and further details are contained in Atmospheric Sciences Technical Notes No. 17 a, b, and c (reference 37).

SYNOPTIC FEATURES OF SANTA ANAS

Great Basin High

The most characteristic synoptic feature of Santa Anas is the Great Basin High*. The principal characteristic of this high is a great mass of dry, relatively cool high pressure air that covers the high plateau region. It reverses the usual onshore pressure gradient to one that is offshore and the resulting subsiding outflow of air from the Great Basin flows across the desert and reaches the coast as a very dry wind called the Santa Ana. As the air descends to sea level,

*The Great Basin is defined as that area between the Rockies and the Sierra-Cascade Mountain ranges encompassing southeastern Oregon, southern Idaho, western Utah, and all of Nevada.

it warms adiabatically at the rate of about 5.5°F for each 1,000 feet of descent.

The Great Basin High typically originates when a Pacific maritime anticyclone, usually part of the Pacific High, moves eastward over the Great Basin where it stagnates and builds in response to surface cooling and upper air features. It is not necessary for the original high to come from the Pacific; it sometimes originates in Canada or the Great Basin High may even have no apparent forerunner at all; it may build only in response to complex thermal patterns higher up. Nor is it necessary for the Great Basin High to be an isolated high pressure center--it frequently shows up as an extension of a large, cold high centered in Wyoming or southern Canada and is also often connected on weather maps to a weakened offshore Pacific High.

The higher the pressures of the Great Basin High, the greater the tendency for air to flow from land to sea. Basin pressures in excess of 1035 mb (millibars) are usually sufficient to cause a Santa Ana, if other considerations are favorable. Typically when highs move inland from the Pacific, the central pressure normally increases by 5 to 20 mb. One of the first indications of such rises will be strong positive pressure tendencies on hourly reports of Great Basin stations and on Weather Service surface maps transmitted every 3 hours. Other evidence is surface advection of cold air over the plateau which normally leads to pressure increase. For this reason, it is generally considered that the colder the Great Basin High, the better the chances for a Santa Ana.

High pressure areas over the Great Basin strong enough to cause Santa Ana winds may occur anytime from early fall through late spring but are most frequent in late fall and winter.

Frontal Passages

The movement of a high pressure area or new air mass into the Great Basin is often preceded by the passage of a front representing the leading edge of the new air. These fronts typically weaken, in terms of visible weather such as clouds and rain, as they move southward. By the time they approach central California, they are frequently difficult to define and are accompanied by few clouds, being discernible by only the most careful application of observations, analysis, and continuity. Even when such "dry" fronts are not discernible, a trough in the westerlies at upper levels almost always marks the forward progress of the new air mass. The purpose of keeping track of these fronts and upper troughs, aside from forecasting immediate weather, is to determine if high pressure is indeed continuing to move toward the Great Basin where it might build into a Great Basin High. Thus the chances of the timing of a future Santa Ana are related to these fronts and troughs, some time usually being required for the Great Basin High to build sufficiently to produce the dry, subsiding

or mass that brings a Santa Ana. Only when a high pushes down from the continental interior is the frontal boundary also the Santa Ana boundary.

The following useful remarks concern fronts that precede buildup of high pressures over the Great Basin that result in most Santa Anas.

Northeast-Southwest Frontal Orientation

The most frequent frontal orientation preceding buildup of a Great Basin High is from the northeast to southwest. Generally, it is also the most frequent frontal orientation observed at Point Mugu's latitude regardless of weather, and it is indicative of a westerly or northwesterly flow aloft. In these situations, the postfrontal high pressure area has a Pacific maritime origin. As the High moves inland toward the Great Basin, it undergoes a certain amount of drying and cooling. It usually takes 12 to 36 hours for the air mass to be modified and for the High to build sufficiently to cause an offshore flow in coastal southern California. A rather typical sequence of events for a northeast-southwest oriented front leading to a Santa Ana is illustrated in figures 5-1(a) through 5-1(d). Note how a portion of the Pacific High modifies into a strong Great Basin High following passage of the front.

East-West Frontal Orientation

Occasionally, cold fronts will pass Point Mugu that are oriented east-west. High pressure areas to the north of (behind) the front are often a blend of both marine and continental characteristics and usually are stronger than their purely marine counterparts. Thus, as the high pressure area moves toward the Great Basin, less building of pressures is required to produce a Santa Ana. In other words, Santa Ana winds will likely occur sooner after passage of an east-west front than a northeast-southwest front, with 6 to 18 hours being a typical time from passage of front to onset of Santa Ana. This is counteracted partially by a tendency of east-west fronts to move southward a little more slowly. In addition, there is usually less visible "weather" associated with them and they are therefore more difficult to track. All available hourly and special surface reports and upper air information for Nevada and central and southern California should be used in determining frontal position and progress. In the event that the front cannot be found through comparison of data from reporting stations, it should be extrapolated forward by continuity.

"Back Door" Fronts--Southeast-Northwest or South-North Orientation

"Back door" fronts are those that approach Point Mugu and southern California from the east and are oriented either southeast-northwest or south-north. Although an infrequent occurrence, they are of special importance to the Santa Ana problem. Due to the completely continental nature of high pressure areas located to the rear of the front, these highs are usually quite cold and dry, pressures are very high, and

furthermore they are already positioned over the Great Basin when the front reaches southern California. This means that Santa Ana winds begin blowing immediately or very shortly after passage of the front.

Although back door fronts are frequently dry in terms of precipitation, the very low dewpoints and strong northeast winds in the cold air usually permit easy identification of the frontal position. Occasionally, back door fronts are accompanied by cumulus clouds and showers since they are usually associated with northeast cyclonic flow aloft about a closed low over the extreme southwest United States or northwest Mexico. The presence of such clouds and rain usually raises anew the question of whether the northeasterlies that follow are a real Santa Ana, a pseudo, or "cyclonic" Santa Ana, or just a gradient wind.

Even though northeast winds blow almost immediately following passage of a back door front, the timing of Santa Ana onset is still a very difficult forecast problem. This is because back door fronts often move very slowly, sometimes taking a day and a half to traverse the 265 nmi from Las Vegas to Point Mugu. A classic example of this occurred during the fall of 1959. On 6 November, the leading edge of a cold continental high advanced toward the southern California coastal regions from the east. Accordingly, Santa Ana winds were forecast to commence at Point Mugu during the morning of 8 November. However, it was not until 1945 PST on the 9th that the front actually passed through the local area, at which time the Santa Ana began. Thus the original forecast for the onset time was about 36 hours premature. At the time the original forecast was issued, weather stations in northern Nevada recorded surface pressures more than 20 mb higher than pressures at Point Mugu. This pressure difference increased to more than 30 mb before frontal passage and Santa Ana onset at Point Mugu. Once the winds actually commenced, the highest hourly maximum speed recorded was 50 knots with gusts to 66 knots--highest sustained wind and one of the highest gusts ever recorded at Point Mugu.*

Wet Fronts and Santa Anas

The majority of all frontal passages at Point Mugu are dry in the sense that relatively few clouds

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*Strong winds were recorded more frequently before 10 July 1962 than since that date, with many of the exceptionally high speeds never again being duplicated. The change is attributed to the relocation on that date of the AN/UMQ-5 wind instrumentation from atop control towers or hangar roofs (elevations near 100 feet MSL) to the present runway location (elevation 26 feet MSL). It is therefore believed that winds recorded before the change in location are not representative of true surface winds but are instead representative of conditions about 100 feet up (references 31, 57).

and no rain are produced locally. Not surprisingly then, the majority of frontal passages that precede Santa Anas at Point Mugu are also dry. Unfortunately, this has led at times to the notion that if a front is not dry, no Santa Ana will occur. Statistics show however, (reference 38) that about one of every four active, or wet, fronts are followed by Santa Anas within 4 days. Some of these fronts even produce moderate amounts of precipitation. A good example was a Santa Ana that began during the morning of 28 November 1960, just 45 hours after passage of a front which left 1.02 inches of rain at Point Mugu.

In general, with ridging over the west coast, fronts preceding Santa Anas are likely to be dry; during periods of more cyclonic activity, fronts preceding Santa Anas are more likely to be wet; thus some of the latter Santa Anas are not of the typical or classical variety.

Destruction Of Inversion Due To Strong Subsidence--A Frontal Passage From Above

The inversion layer separates two different air masses: the cool, moist marine layer below from the warm, dry subsiding air above. In this sense, the inversion can be thought of as a front. When the strongly subsiding offshore flow from a Great Basin High begins in the local area, the inversion lowers as the marine layer becomes increasingly shallower. When the offshore flow of air lowers to the surface, the inversion is effectively driven into the ground and destroyed and we say the Santa Ana has begun. The vertical passage of the inversion before Santa Ana onset may be thought of as yet another frontal passage. The importance of the inversion to Santa Anas will be discussed later in this section.

Ridge Aloft/Subsidence

Nearly every Great Basin High and Santa Ana is associated with a pronounced ridge aloft situated over or just off the West Coast and a deep trough located dowstream further to the east. A subsiding current of air which warms adiabatically comes from the forward side of this ridge and feeds into the low level outflow of the Great Basin High. The more pronounced this subsidence, the more enhanced are the Santa Ana winds at the coast.

Nearly every Santa Ana is associated with this pattern of ridge and trough aloft, but variations--sometimes subtle, sometimes substantial--in position and strength of these upper air features do occur, and produce changes in the character of the Santa Ana winds. When the downstream trough is located rather close to Point Mugu, there is less subsidence from above and the offshore flow tends to be somewhat cyclonic in nature. The air is likely to be colder and more unstable and there may be convective cloudiness and showers. Under these circumstances, the dry northeast surface wind is often said not to be a true Santa Ana. With the trough located further to the

east and strong subsidence over the West Coast, offshore flow is usually warmer, drier, and more generally classified as a typical Santa Ana. All too frequently, one upper air pattern will, with time, blend to the other. Clearly, the dividing line between classic and pseudo Santa Ana is ill-defined. A more detailed discussion of the non-typical or borderline Santa Ana appears later in this section.

Santa Anas are probably easier to forecast from upper air "progs" (prognoses) than from surface maps. One of the best indicators of an impending Santa Ana situation is the occurrence of a strong or sharp ridge moving toward the coast within the belt of westerlies. When a long wave ridge is firmly entrenched over or just off the West Coast, short wave troughs travelling across the top may temporarily flatten it, but the ridge usually rebuilds sharply soon afterwards, and often results in renewed Santa Anas. The short wave troughs are cold tongues associated with the surface fronts which precede establishment or re-establishment of a Great Basin High as discussed earlier.

Example Of A Santa Ana Development And Abatement

The roles of the Great Basin High and upper air features in causing Santa Anas at Point Mugu are illustrated in the following typical example. Surface weather maps 12 hours apart for 20-24 December 1963 and two 500-mb maps analyzed during the same period are presented as figures 5-1 through 5-2.

After a few days with fog and hazy conditions, a weak front passed Point Mugu during the night of 20 December. This front had the typical northeast-southwest orientation discussed earlier and marked the leading edge of a maritime high pressure area of only ordinary intensity (figure 5-1). By midnight of 21 December, visibilities began to improve in the fresh post-frontal air mass but temperatures, dewpoints, and winds remained essentially the same. As the high pressure area followed the front inland, pressures began to build over the Great Basin area (figures 5-1(b) and 5-1(c)). Meanwhile, the upper trough associated with the surface front that was located over the West Coast on the 20th (figure 5-2(a)) gradually deepened as it moved inland and was followed by a strong, enlarging ridge. The northerly flow that developed aloft prevented the building surface high from moving eastward. This cold high continued to build until Great Basin pressures became considerably higher than pressures at or off the coast. The stage was set for a flow of air from land to sea.

At about 2000 PST on the 21st, the surface wind at Point Mugu went to light northerly and the dewpoint dropped more than 20 degrees in one hour. This marked the arrival of the very dry Santa Ana air mass. During the early morning hours of 22 December dry, gusty foehn-type winds began blowing out of the northeast with gusts increasing to 30 knots by mid-morning. By afternoon, pressures at the center of the Great Basin High increased to 1044 mb. Figure 5-2(b) shows the 500-mb pattern at the time of maximum

(a)

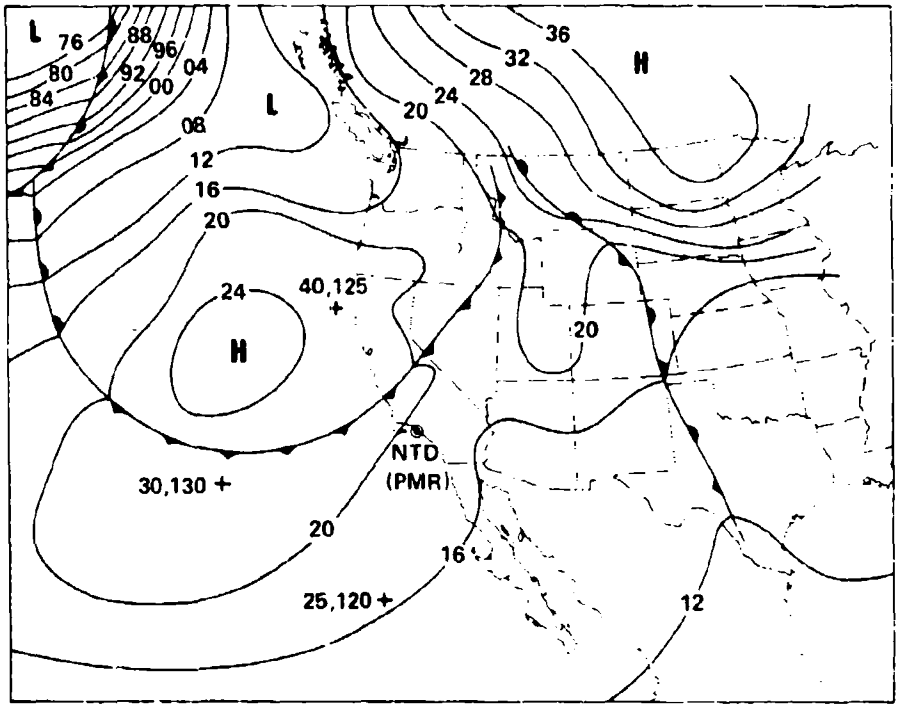


Figure 5-1(a). 20 December 1963, 1600 PST.

(b)

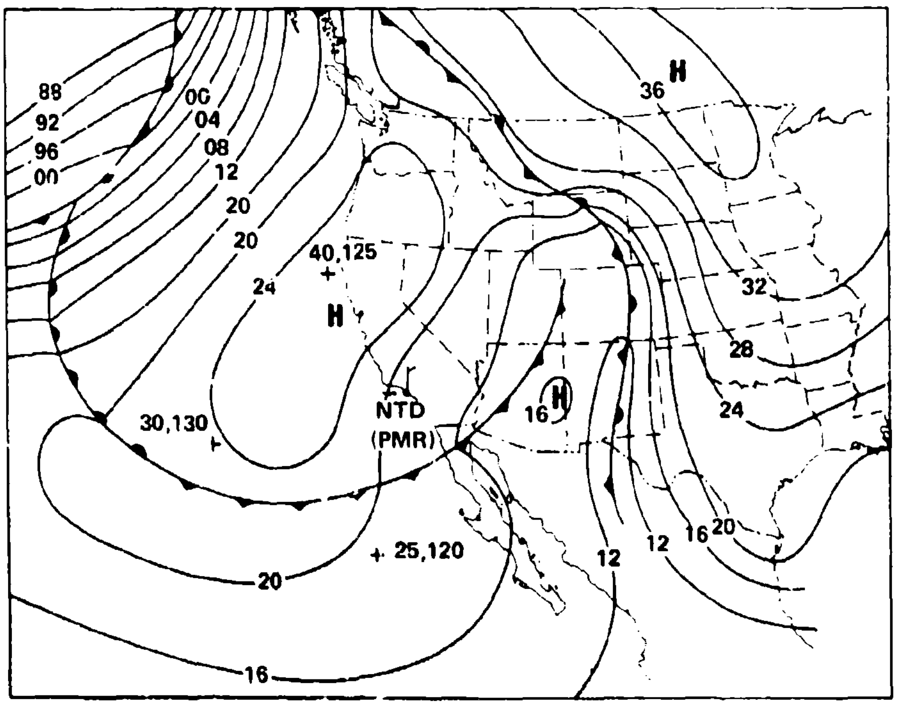


Figure 5-1(b). 21 December 1963, 0400 PST.

FIGURE 5-1 (a,b)

FIGURE 5-1 (c,d)

(c)

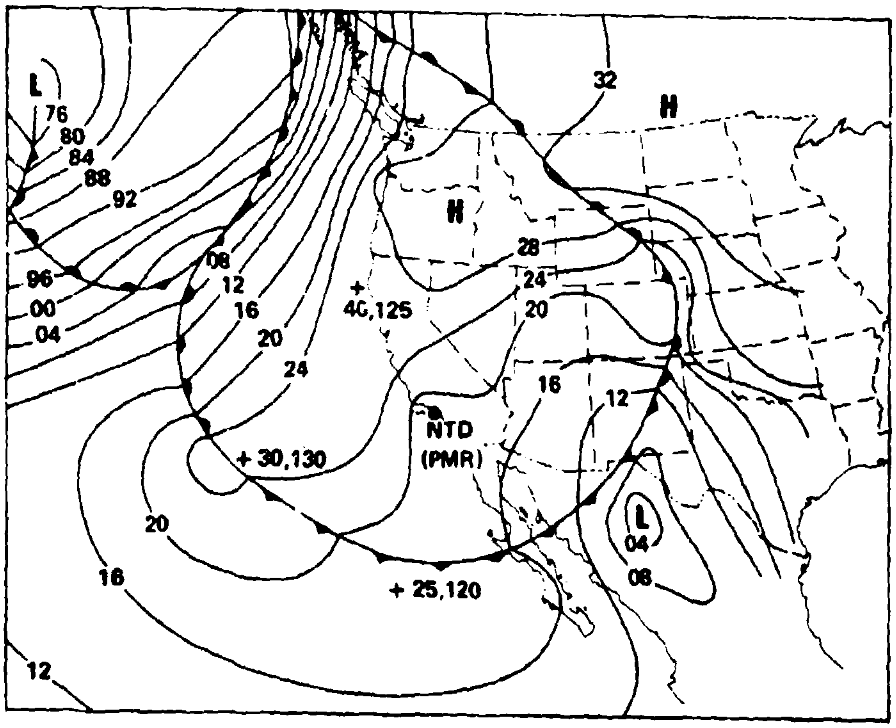


Figure 5-1(c). 21 December 1963, 1600 PST.

(d)

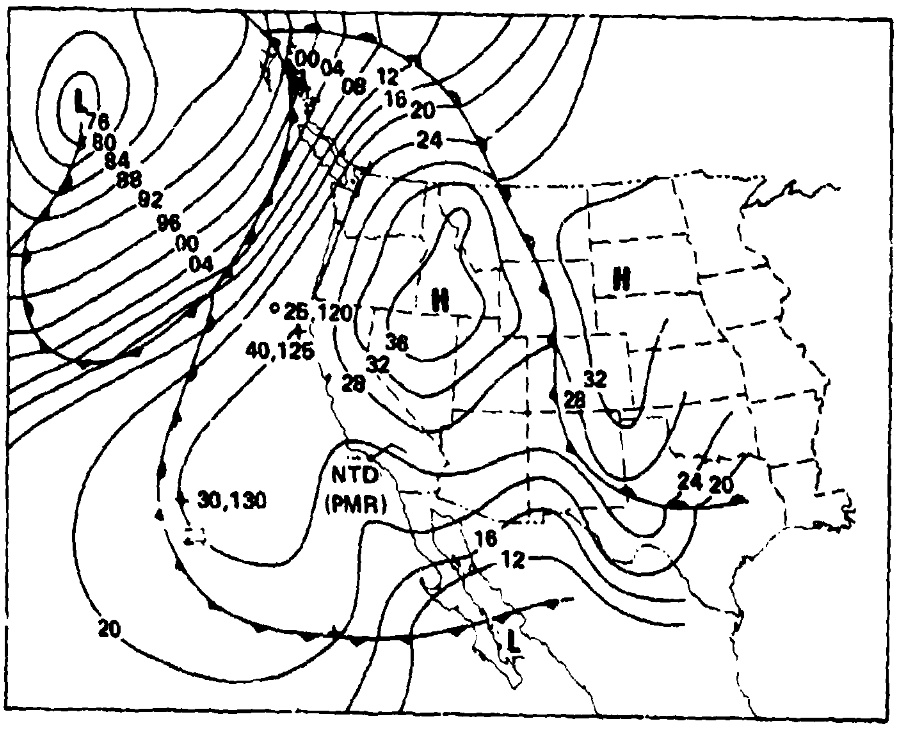


Figure 5-1(d). 22 December 1963, 0400 PST.

(e)

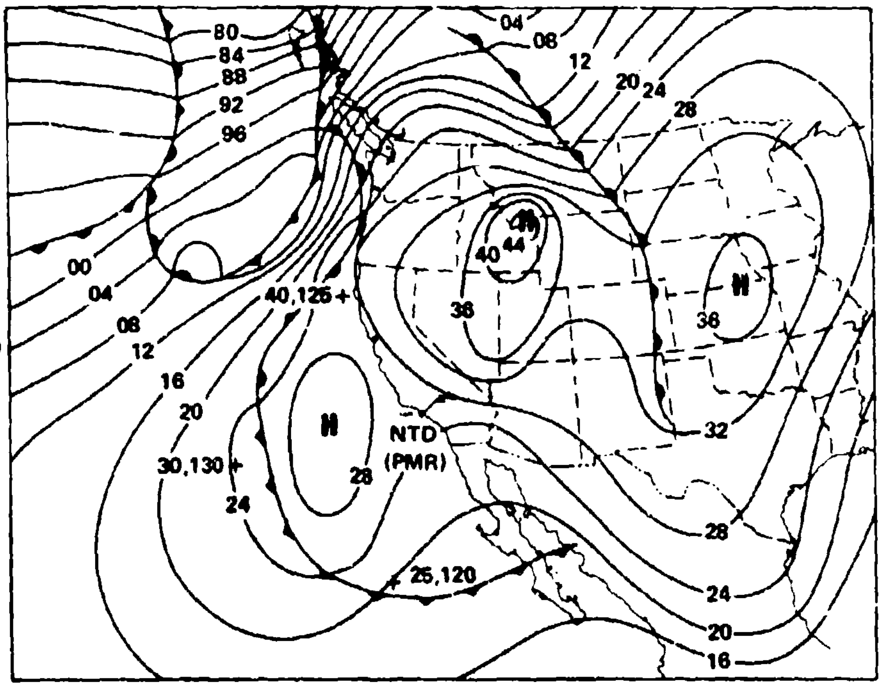


Figure 5-1(e). 22 December 1963, 1600 PST.

(f)

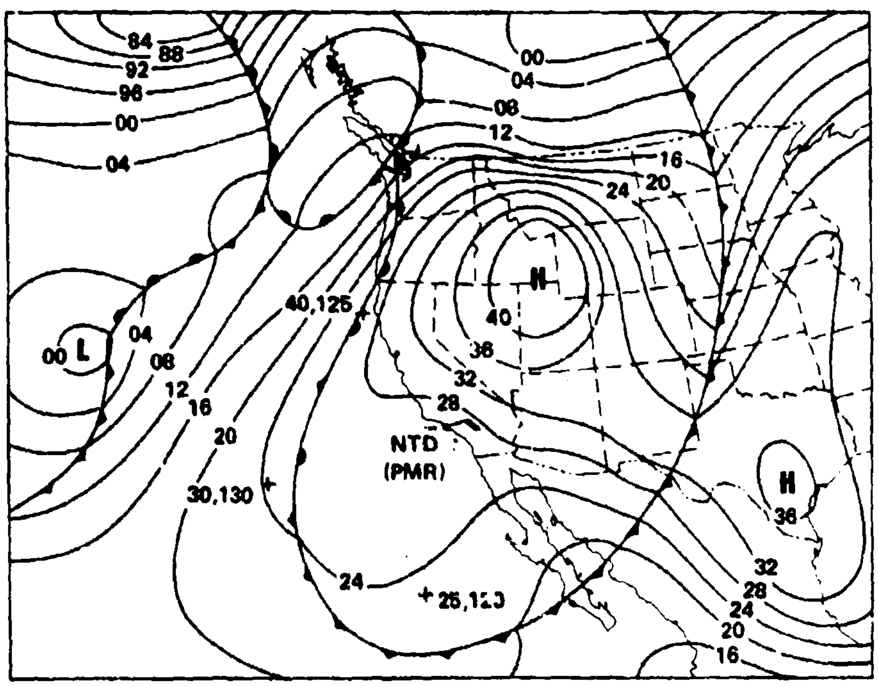


Figure 5-1(f). 23 December 1963, 0400 PST.

FIGURE 5-1 (e,f)

FIGURE 5-1 (g,h)

(g)

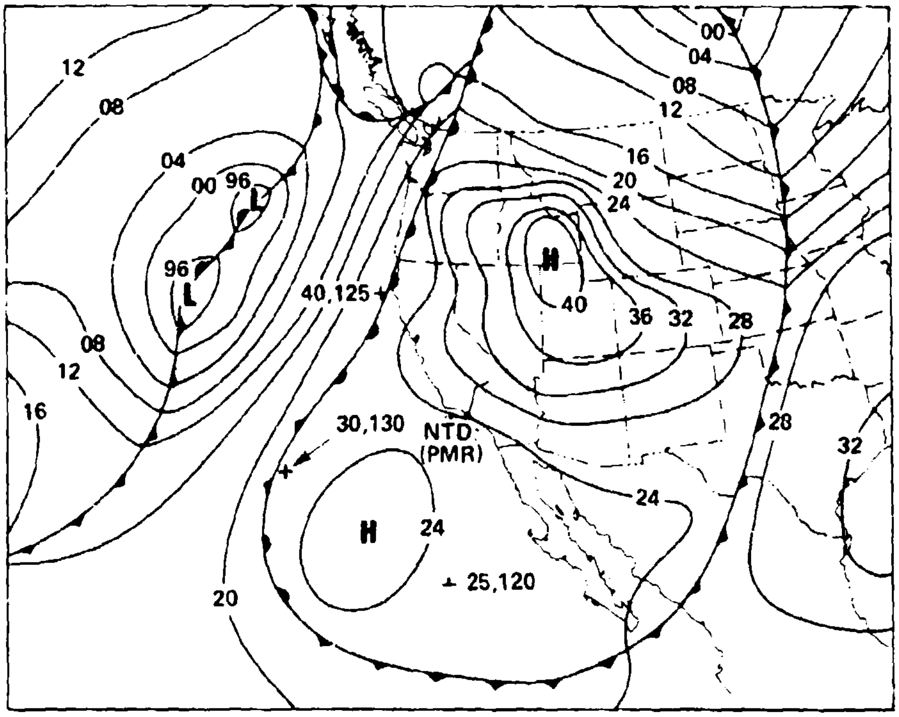


Figure 5-1(g). 23 December 1963, 1600 PST.

(h)

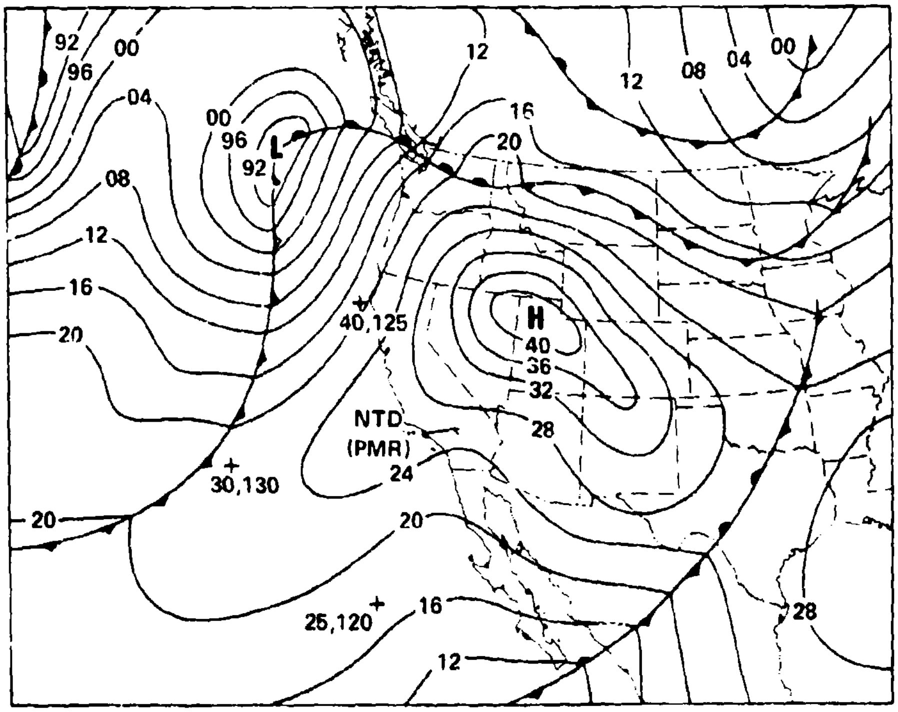
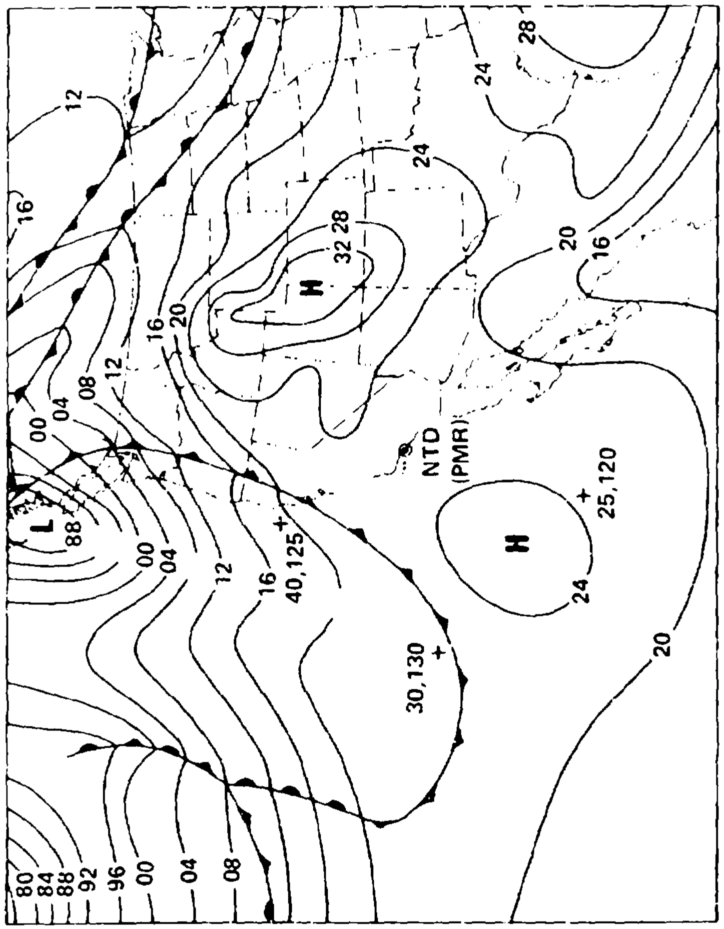


Figure 5-1(h). 24 December 1963, 0400 PST.



(i)

Figure 5-1(i). 24 December 1963, 1600 PST.

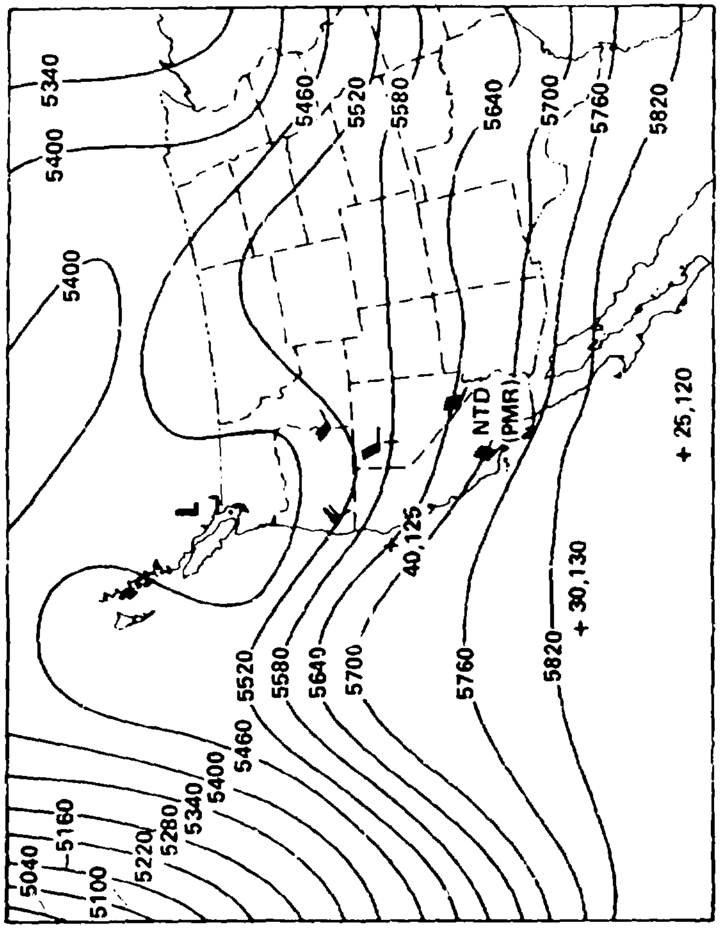
development of the Great Basin High and the day of the strongest winds at Point Mugu. It is evident that the amplifying ridge has moved farther inland over the northwest states than it has over the southwest. This is a rather typical occurrence and results in northerly flow aloft over Point Mugu with considerable subsidence in lower layers. Figure 5-1(e) shows the surface analysis at the same time.

Figures 5-1(g) through 5-1(i) show the gradual deterioration and movement to the east of the Great Basin High as the upper ridge continued to move inland and bring warmer air over the high plateau. At the same time, the northerly flow aloft began to break down into a more zonal west-east flow.

On 24 December, when the offshore pressure gradient was reduced and the Great Basin High considerably weakened, the Santa Ana came to an end and the daily sea-breeze regime took over once again. Higher dewpoints, southwest winds, and generally more marine conditions returned to Point Mugu.

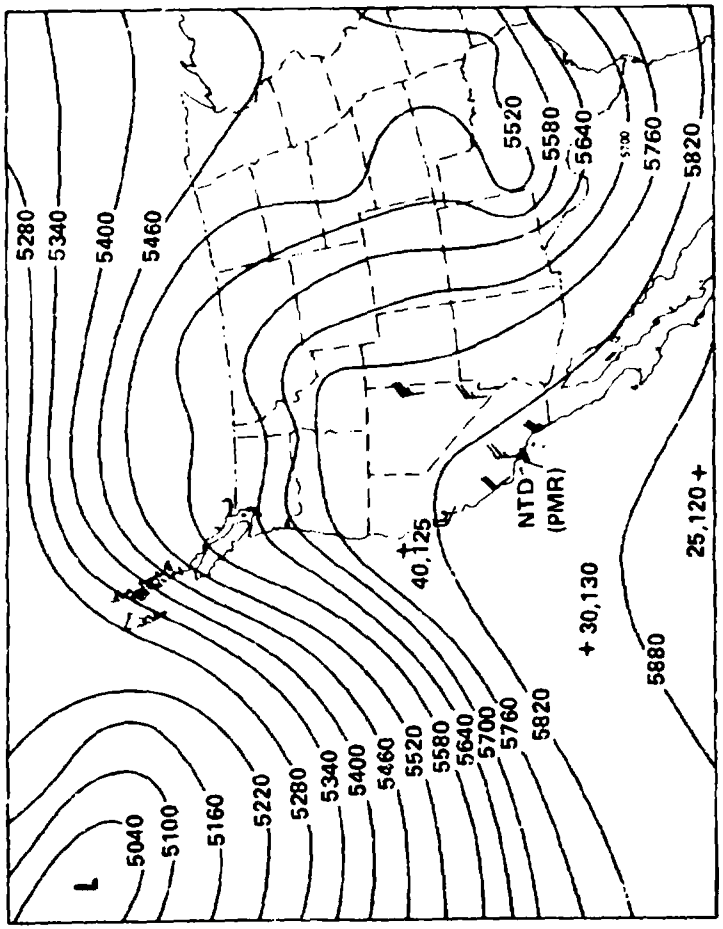
The preceding description of the order of events associated with a specific Santa Ana is common to most Santa Anas. Sometimes this chain of events occurs faster or slower than indicated here and may

FIGURE 5-2 (a,b)



(a)

Figure 5-2(a). 20 December 1963, 1600 PST.



(b)

Figure 5-2(b). 22 December 1963, 1600 PST.

result in a Santa Ana of shorter or longer duration. The Great Basin High may also originate from the continental interior as discussed earlier. But when the very gross features and most general synoptic characteristics are considered, all Santa Anas look pretty much alike.

Upper Winds

In a typical Santa Ana situation such as the one just described, Point Mugu is situated under the forward side of a ridge and has northerly winds aloft. The presence of such northerly, and especially northeasterly, winds aloft during the cooler months has often been taken as one of the favorable signs of an impending Santa Ana, other factors being also favorable. However, when individual cases and statistics are examined, it becomes apparent that there are a number of upper air wind directions which can be associated with particular Santa Anas. The few specific correlations available are more appropriately presented under the following sections of "Weather Associated With Santa Anas." Suffice it to say that as far as Santa Ana onset is concerned, it appears that it is more likely to occur at Point Mugu if the belt of strong northerlies (including both northwesterlies and northeasterlies) preceding a ridge lie over southern California as compared with such locations as Arizona or New Mexico several hundred miles to the east.

Orientation Of Pressure Gradient

The establishment of a Great Basin High changes the surface pressure gradient from one that is onshore to one that is partially or wholly offshore. But whether Point Mugu experiences Santa Ana winds depends on the orientation of the isobars in southern California. On such days Los Angeles, Santa Monica, and the San Fernando Valley often experience strong, dry, northerly, downslope winds which appear to resemble a Santa Ana while Point Mugu often experiences strong onshore westerlies. Then on the following day or so, when the high has built strongly over the Great Basin and isobars are oriented more east-west or even southeast-northwest, Point Mugu experiences strong, northeast Santa Ana winds while much of the nearby Los Angeles Basin experiences light variable winds or only sporadic northeasterlies.

Establishment of a thermal trough inland may change a potential Santa Ana situation to a marine,

onshore flow over the local area by re-orienting the isobars or pressure field.

In all of these situations, the wind at Point Mugu is affected by the large scale wind flow and its relation to topographic features such as mountains, passes and canyons, and plains. Specific local topographic features and their effects on local winds will be discussed in more detail under "Spatial Variations."

"Thermal Support" For Santa Anas

One of the terms often used by the National Weather Service (Los Angeles office) in connection with Santa Ana probability is "thermal support" (reference 39). An example of its use is shown below in an FPUS3 forecast received at Point Mugu on 7 January 1971. The term should be particularly helpful to forecasters due to its simplicity: it is defined as the sum of two differences. One of these is the difference in degrees between 700-mb temperatures at Yucca Flats (LSV) (Nevada), and Vandenberg AFB (California) (VGB); and the second one is the difference in millibars between the surface pressure at Tonopah (TPH) and Los Angeles (LAX). The inland station (LSV or TPH) is assumed to be colder and higher in pressure, respectively. If the arithmetic sum of the two differences is equal to or greater than "12," it is considered to be favorable for a Santa Ana. As an example, at 1200Z on 5 January, the 700-mb temperatures were -15°C at LSV and -02°C at VBG. The surface pressures were 1028 mb at TPH and 1023 mb at LAX. The arithmetic sum of the two differences in this case was therefore [(-)15-(-)02] + [1028-1023] = 13+5 = 18. This number is greater than 12, and therefore the Santa Ana has "thermal support." At the time, actual Point Mugu winds were northeast at 13 knots with gusts to 20 knots, and the day's peak gust of 34 knots was recorded later in the morning. Winds on Laguna Peak reached at least 51 knots. Following is the EPUS3 regional forecast issued on 7 January after the Santa Ana ended.

```
FPUS3 KLAX Ø7Ø959
AGREE WITH FXUS1 BY BROWN IN SLO RETROGRESSION
OF LGWV FEATURES OVR WRN US. FLATTENING OF RDG
ERN PAC BY Ø812ØØZ PART OF CHG IN PAT. DURG NXT
48 HRS UPR FLOW OVR DIST CONTG NLY OF RLTVLY
COLD DRY AIR. WILL DCR GUSTY SANTA ANA WNDS TDA
AS OFSHR PRES GRADS DCR AND THERMAL SUPPORT
NRLY GONE. CONTD FAIR WX AND BLO SSNL TEMPS.
PROBS ØØØ.
```

The combination of temperature and pressure is appropriate as a guide to predicting Santa Anas since it agrees with our subjective but well accepted view of Santa Ana winds as being most likely when pressures are much higher and air much colder over the Great Basin than they are at the coast. Inspection of the 700-mb temperatures can lead to inferences about the warmth or coolness of the Santa Ana in addition to the likelihood of onset. Past experience has indicated that the thermal support criterion for Santa Ana occurrence verifies well for predicting the start of Santa Anas in southern California but less so for their

ending. In applying this criterion to local use it should be pointed out that a positive indication of Santa Anas (thermal support value of 12 or more) should be interpreted to apply to southern California as a whole but that it cannot account for individual and local differences in occurrence, or strength of winds within the Los Angeles Basin and at different locations along the coast, including Point Mugu.

WEATHER ASSOCIATED WITH SANTA ANAS

Seasonal Distribution

Any description of the weather associated with Santa Anas should be preceded by some brief statistics on the seasonal distribution of their occurrence so that the forecaster may compare those weather characteristics he finds with what he might expect on an average day for any particular time of year. As mentioned earlier, these statistics and most of those in the following sections are based on data and results compiled in reference 37.

Briefly, Santa Anas are primarily a late autumn or winter phenomenon. The are most frequent in December and January but also usually occur on at least a few days of October, November, February and March (see figure 5-3). There is considerable variation from year to year in monthly totals, depending upon synoptic situations and long wave patterns. Since the fall of 1948, the earliest time for which statistics could be compiled, there have been only two Santa Anas recorded at Point Mugu during the summer season, 22-23 September 1968 and 22 September 1970. In each case, Santa Ana onset occurred only hours before summer officially ended. At the other side of the calendar year, the latest Santa Ana was on 18 June (1957). These occurrences illustrate that Santa Anas are not completely restricted to the cooler months.

In an average year, the individual monthly totals add up to 16 Santa Anas for the year. Yearly totals also vary widely about the average, as do individual months.

Diurnal Variations Of Santa Anas

As with stratus during the warmer months, Santa Ana conditions also exhibit a dependency on time of day. At Point Mugu, Santa Anas nearly always begin at night or morning and end at midday. This tendency is illustrated in figure 5-4. Since there is no obvious reason to expect synoptic features to exhibit such a time dependency, it appears that the diurnal land-sea-breeze regime in response to the daily solar heating cycle is again responsible. Thus the normal night and early morning land breeze augment any tendency for an offshore flow due to synoptic patterns or local topography, and the usual daytime sea breeze interferes with that same tendency for offshore winds.

When onset and ending times are looked at in more detail, significant month-to-month variations

FIGURE 5-3

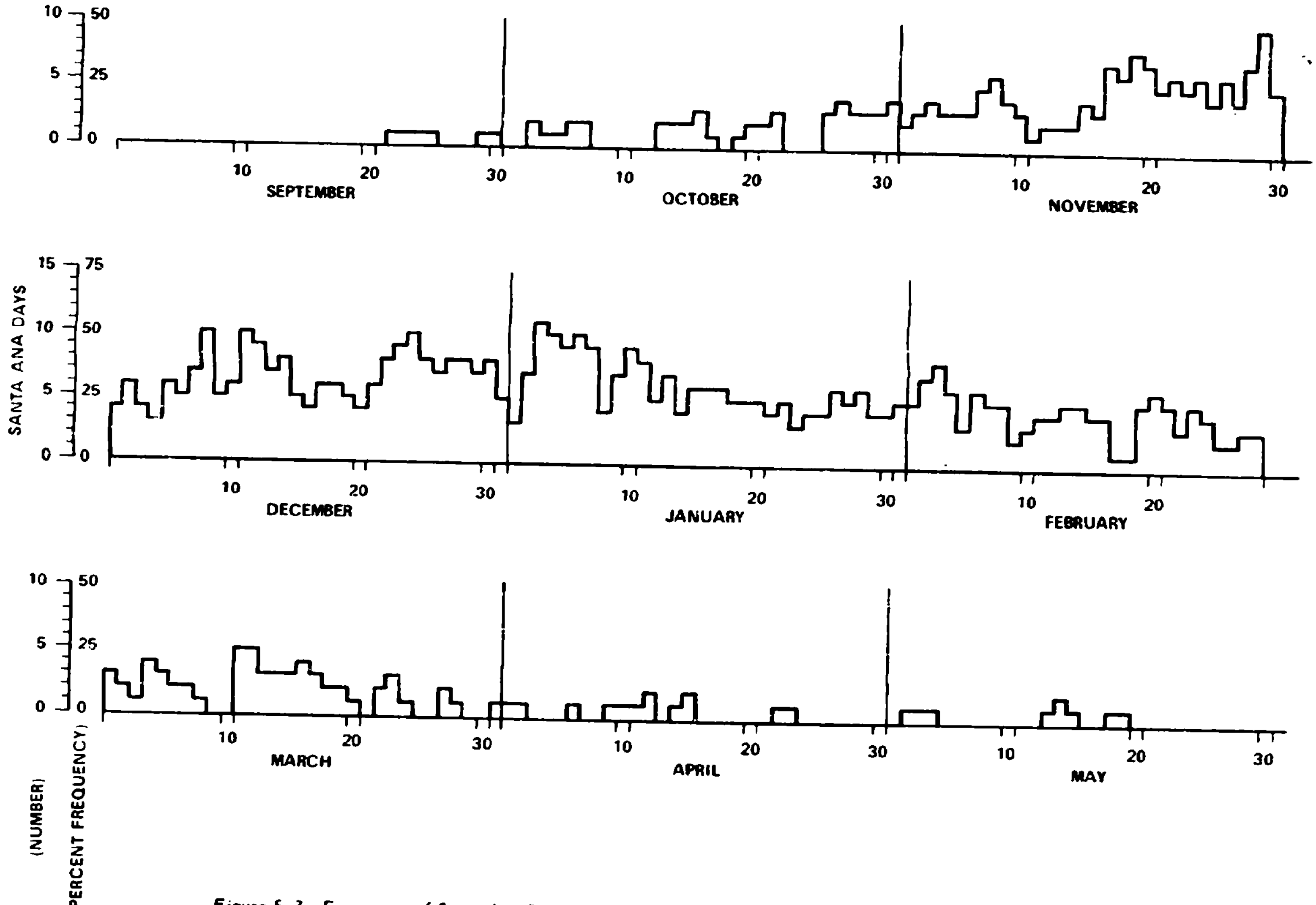


Figure 5-3. Frequency of Santa Ana Days at Point Mugu by Day of Month for October 1948 – September 1968. (Reference 37.)

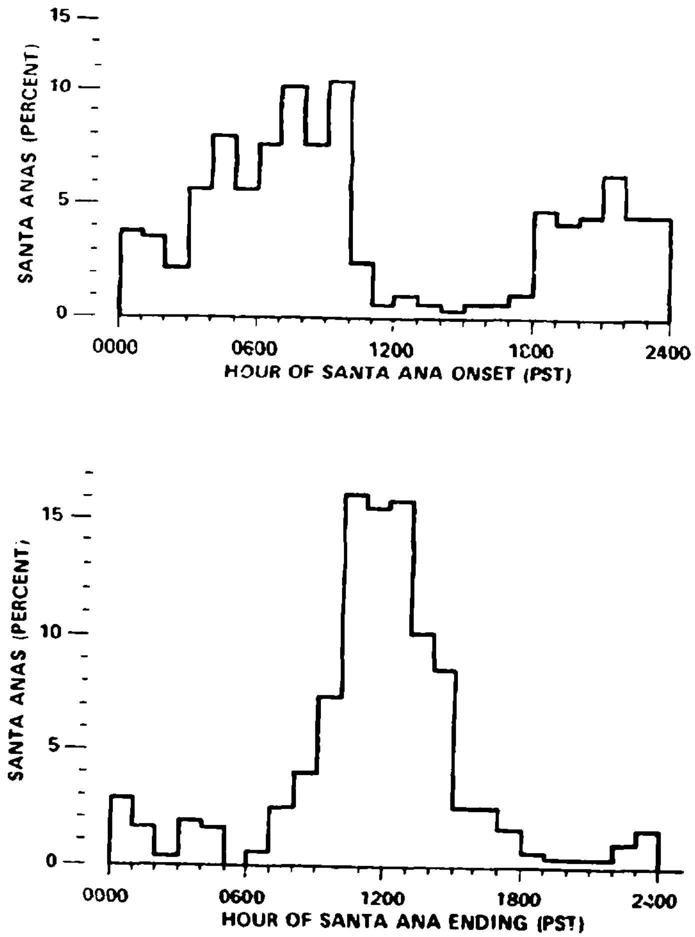


Figure 5-4. Hours of Onset and Ending of Santa Ana Regimes at Point Mugu. (Reference 37.)

are found (figure 5-5). In autumn and spring months, onset times show a pronounced maximum of occurrence near sunrise, whereas during the peak of the Santa Ana season, December and January, the onset times before midnight predominate. These variations should be considered very important to the forecaster and may be explained by considering seasonal factors of heating and cooling.

As was stated before, synoptic-scale patterns and developments should be largely independent of time of day; however, wind regimes near the surface may well be affected by localized diurnal patterns. Thus we may envision a Santa Ana flow aloft which reaches the surface when the low level land-sea-breeze circulation permits. As long as the sea breeze and relatively dense marine layer predominate, the Santa Ana flow remains aloft.

The normal sea breeze is best developed and most regular in summer when synoptic influences are minimal and daytime heating is intense. On the other hand, the nocturnal land breeze at Point Mugu is most pronounced and consistent in winter when cold air drainage down the slopes of nearby terrain is maximum because of long nights and frequently clear skies. In initially working down to the surface, an incipient Santa Ana thus obtains more reinforcement from the local surface land breeze in winter, and more often reaches the surface during the early hours of

FIGURE 5-5

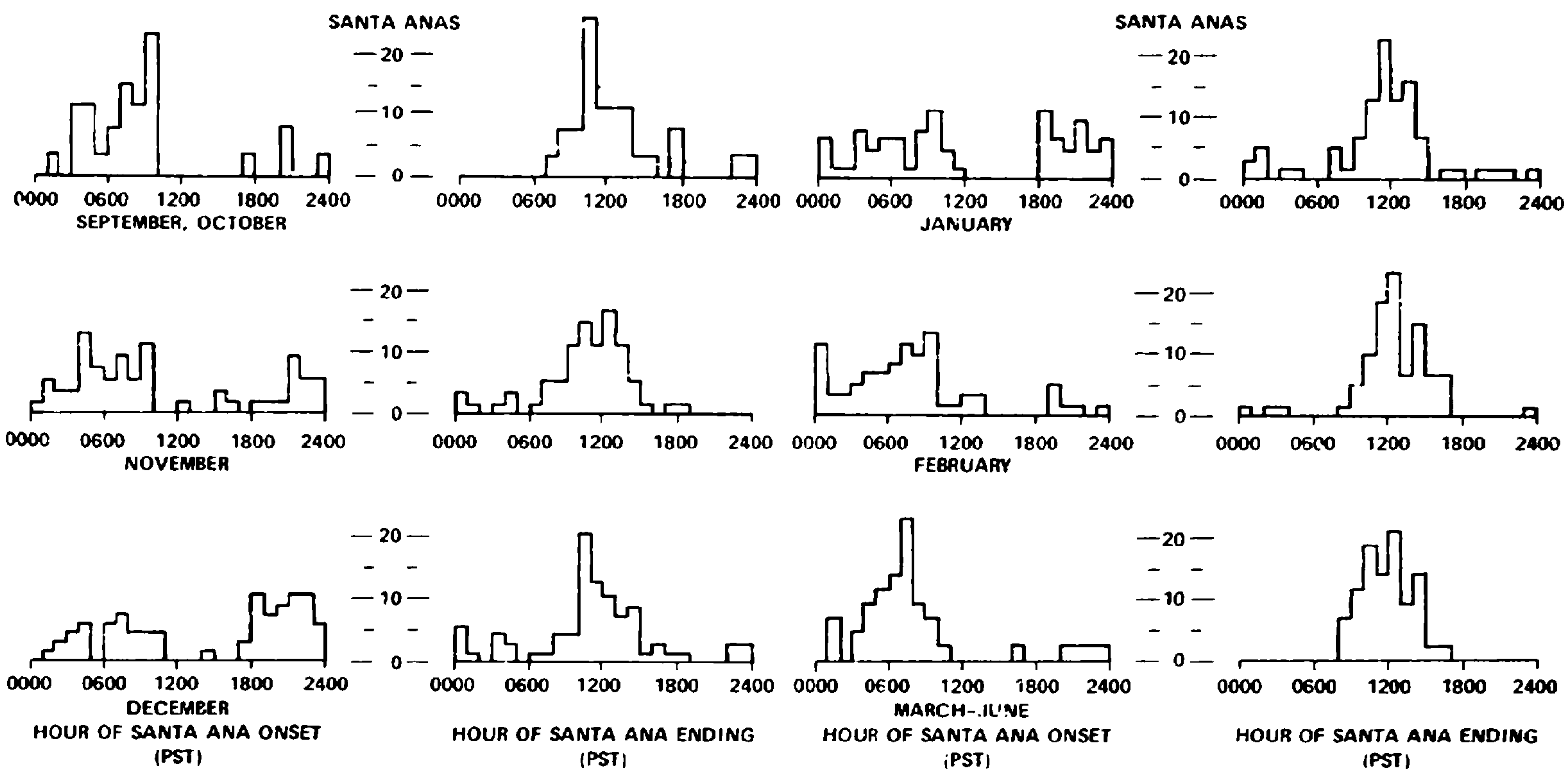


Figure 5-5. Hours of Onset and Ending of Santa Ana Regimes at Point Mugu, by Month. (Reference 37.)

the nightly land breeze. In autumn or spring, the nighttime land breeze may be shallow or weak or non-existent due to low warm inversions, but solar heating of the surface is more effective than in winter, so thermal mixing after sunrise is probably effective in destroying the inversion and triggering the descent of Santa Ana flow aloft.

The midday maximum ending times of Santa Anas is not surprising, since the basic criterion for determining this parameter is a directional shift from offshore to onshore flow and the onshore sea breeze typically blows at this time of day. On a seasonal basis (figure 5-5), it appears that Santa Ana ending times are more variable in winter than in spring or fall. This is attributable to the weaker and more sporadic sea breezes and the much greater influence of the westerlies in winter, as compared with spring and fall when patterns are more stable.

Bursts Versus Regimes

As was just noted in the previous section, a distinct tendency exists for diurnal variation of Santa Ana characteristics. Offshore northeasterlies begin at night or in early morning and blow until midday when the onshore sea breeze takes over. On the other hand, we know from observation and experience that the synoptic features which result in Santa Anas frequently persist for more than a single day and result in periods of Santa Ana winds on two or more successive days. Clearly there is a need to distinguish between the entire synoptic period of Santa Anas and individual or daily periods of northeasterlies. In many cases, they will be the same.

A useful and simple way of distinguishing between these two properties is: a single period of continuous Santa Ana winds is termed a **Santa Ana Burst**; an over-all synoptic episode which consists of one or more such Santa Ana Bursts separated by intervals of not more than 24 hours is termed a **Santa Ana Regime** (reference 37). Much of the succeeding descriptions of Santa Ana weather characteristics distinguish between Bursts and Regimes.

Winds

Of all the characteristics of Santa Anas, wind is probably the one that stands out most in the minds of

the average southern Californian. It is the strong wind that creates high fire and traffic hazards and it is the wind that people associate with abnormal heat and dryness. Certainly it is the speed and gustiness of the wind which has the greatest operational significance at Point Mugu during Santa Anas.

As with nearly all weather features, these winds come in a variety of sizes and intensities. Santa Ana winds may be weak, moderate, or strong, depending on the intensity and orientation of pressure gradients and effects of local topography.

To summarize Santa Ana characteristics into meaningful pictures as presented in reference 37, it was necessary to adopt a meaningful, operationally-oriented definition of a Santa Ana based on winds. The accepted criteria were that winds (1) blew from the northeast quadrant, (2) with a speed of 12 knots or greater, (3) on at least two consecutive hourly observations (although in some cases those with only one hourly report were included), and (4) were accompanied by significantly lower humidities than in the preceding several hours. Note, in these criteria, the *exclusion* of (1) moist, cyclonic "Santa Anas" (to be discussed later), (2) very weak Santa Anas, and (3) those Santa Anas that blew for periods of less than 1 hour and did not appear on an hourly report. Thus the following statistics will be biased slightly toward the more classical, moderate Santa Ana.

Wind Direction

Santa Ana winds at Point Mugu are so heavily biased to the northeast direction that no statistical study is required to summarize directions. Observation and experience reveal that winds almost always come from between 030 and 070 degrees with the remainder of the northeast quadrant being represented primarily during the transition periods of onset and end. Even during the more nontypical "pseudo" Santa Anas, surface winds are usually northeast or east-northeast. And on Laguna Peak (elevation 1,450 feet), wind directions during Santa Anas are virtually identical to the Santa Ana directions recorded below. The consistency of Santa Ana wind directions in the local area is a dirct result of the strong reliance of these winds upon local topography. The Saugus--Newhall and Mint Canyon Passes are northeast of the local area and provide a favorite path for the seaward flow of air from the Great Basin (reference 25). Further discussion on the role of topography appears under "Spatial Variations."

Wind Speed

Discussion of windspeeds attained during Santa Anas must be preceded by a reminder that the official AN/UMQ-5 wind instrumentation was relocated on 10 July 1962 from atop control towers or hangar roofs (elevations near 100 feet MSL) to the present runway

location (elevation 26 feet MSL). Thus, the pre-July 1962 winds are probably representative of conditions around 100 feet and not of true surface conditions. Since the changeover date, surface windspeeds have not attained the peak values that winds in the earlier years did, so the windspeed statistics provided here for Santa Anas are separated in pre-July 1962 and post-July 1962 values. The latter should be used by forecasters as guides to surface conditions in future Santa Anas. That the differences between the two data groups are significant is illustrated in figure 5-6, which shows the peak Santa Ana gusts since July 1962 averaging what the maximum sustained wind averaged for the pre-July 1962 time period.

The frequency distributions of Santa Ana maximum windspeeds are shown in figure 5-7. Since 1962, the most frequent maximum sustained windspeed is in the 15 to 19-knot range; the most frequent maximum gust is in the 25 to 29-knot range. Thus the typical Santa Ana can be expected to result in peak winds that are close to these values. An inspection of the pre-1962 data shows that much higher speeds were measured at the higher location. Approximately 10% of Santa Anas in the early data period had maximum gusts of 50 knots or more, but such a high windspeed value has never been measured at the surface during a Santa Ana since that time.

The breakdown of Santa Ana maximum windspeeds into the more operational categories, "small craft" (to 33 knots), "gale" (34 to 47 knots), and "storm" (48+ knots), should prove useful to the forecaster in assessing the significance of any imminent Santa Ana. As seen from figure 5-8, current pictures of Santa Anas show the majority (two-thirds) to be in the small-craft category, meaning that winds in the majority of cases do not exceed 33 knots, even for gusts. The remainder of Santa Anas (one-third) fit into the gale category with peak gusts no higher than 47 knots. A look at the Santa Anas as determined from the pre-1962 sensor location shows a substantial number in the storm category with peak gusts exceeding 47 knots, a higher frequency in the gale category, and a much reduced frequency in the small-craft class. Thus, Santa Ana intensities as determined from surface winds at our present location are much weaker than one would believe from insp-ction of old weather records and climatological summaries. From July 1962 through September 1968 there had never been a "storm" Santa Ana at Point Mugu. The 49-knot gust recorded at the surface during a Santa Ana on 19 February 1970 represents the first case of a "storm" Santa Ana in recent times and may, in fact, be one of the strongest Santa Anas ever to occur at Point Mugu.

The distribution of windspeeds for individual Santa Ana Bursts is similar to those just discussed for Santa Ana Regimes with one important exception: The speeds average about 5 knots lower. Another point revealed by the statistics in reference 37 is that in multiple-Burst Santa Anas, the strongest winds

FIGURE 5-6

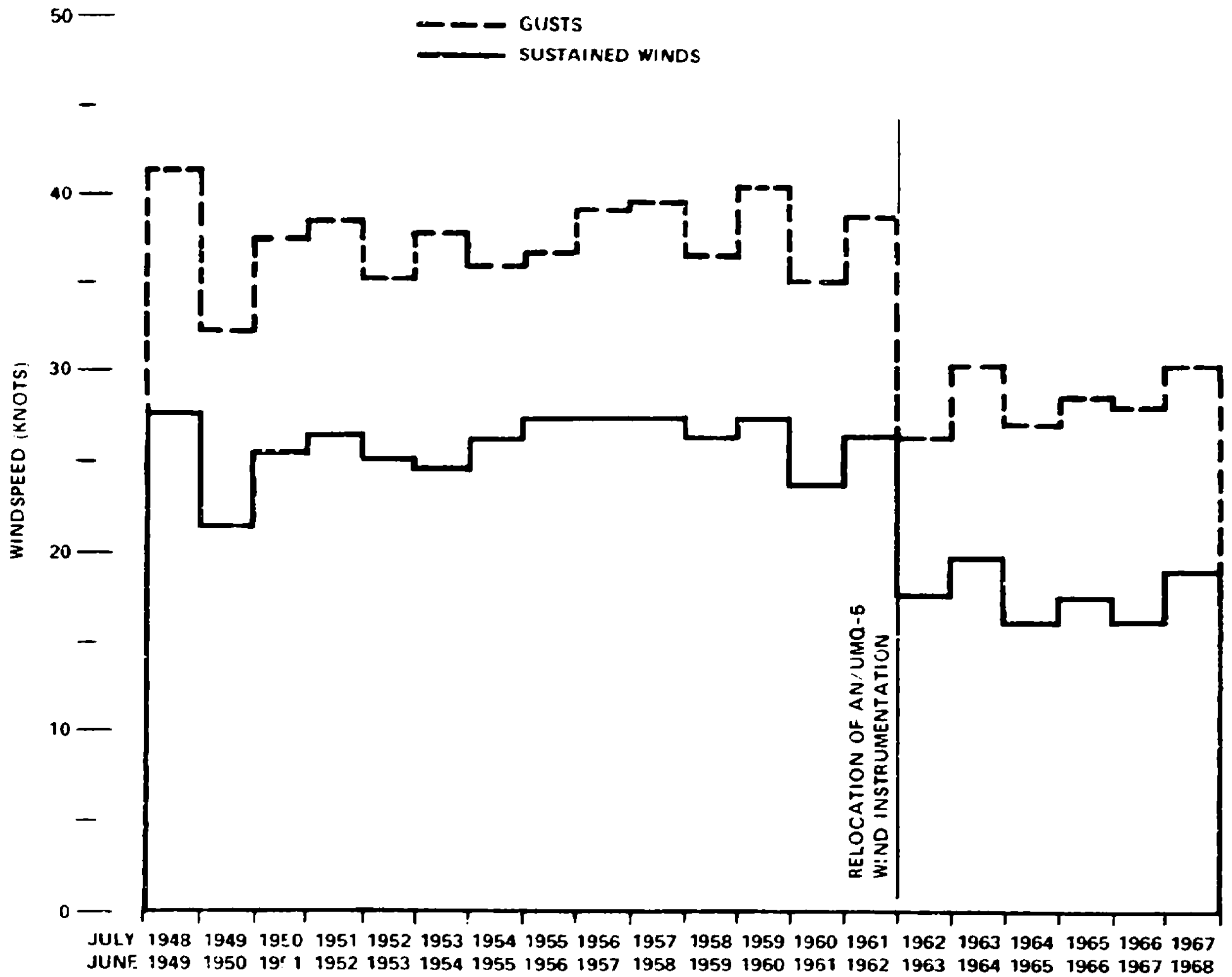


Figure 5-6. Annual Means of Maximum Winds Recorded During 317 Santa Ana Regimes at Point Mugu. (Reference 37.)

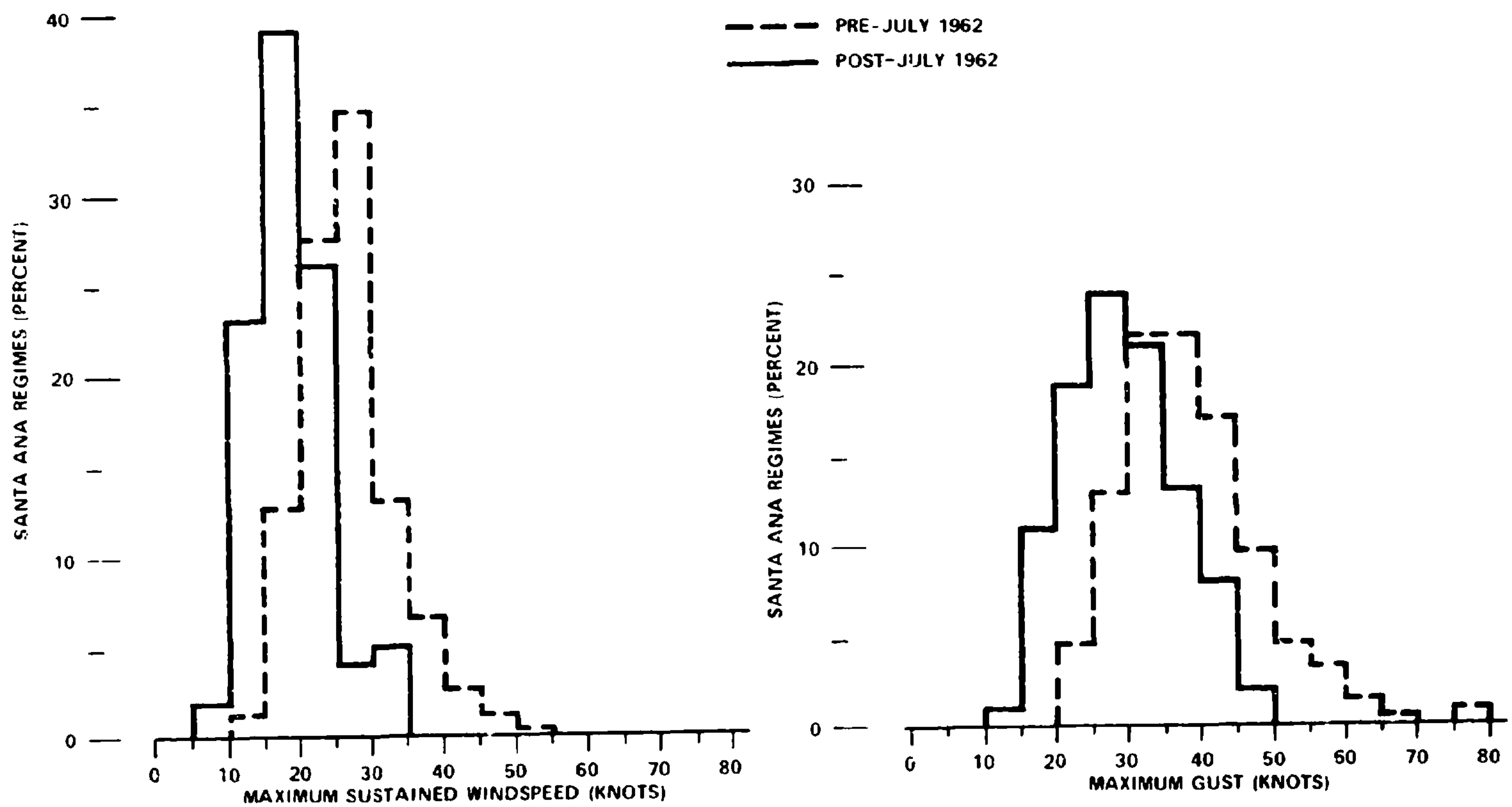


Figure 5-7. Frequency of Maximum Sustained Wind Speeds and Maximum Gusts During Santa Ana Regimes at Point Mugu. (Reference 37.)

FIGURE 5-8

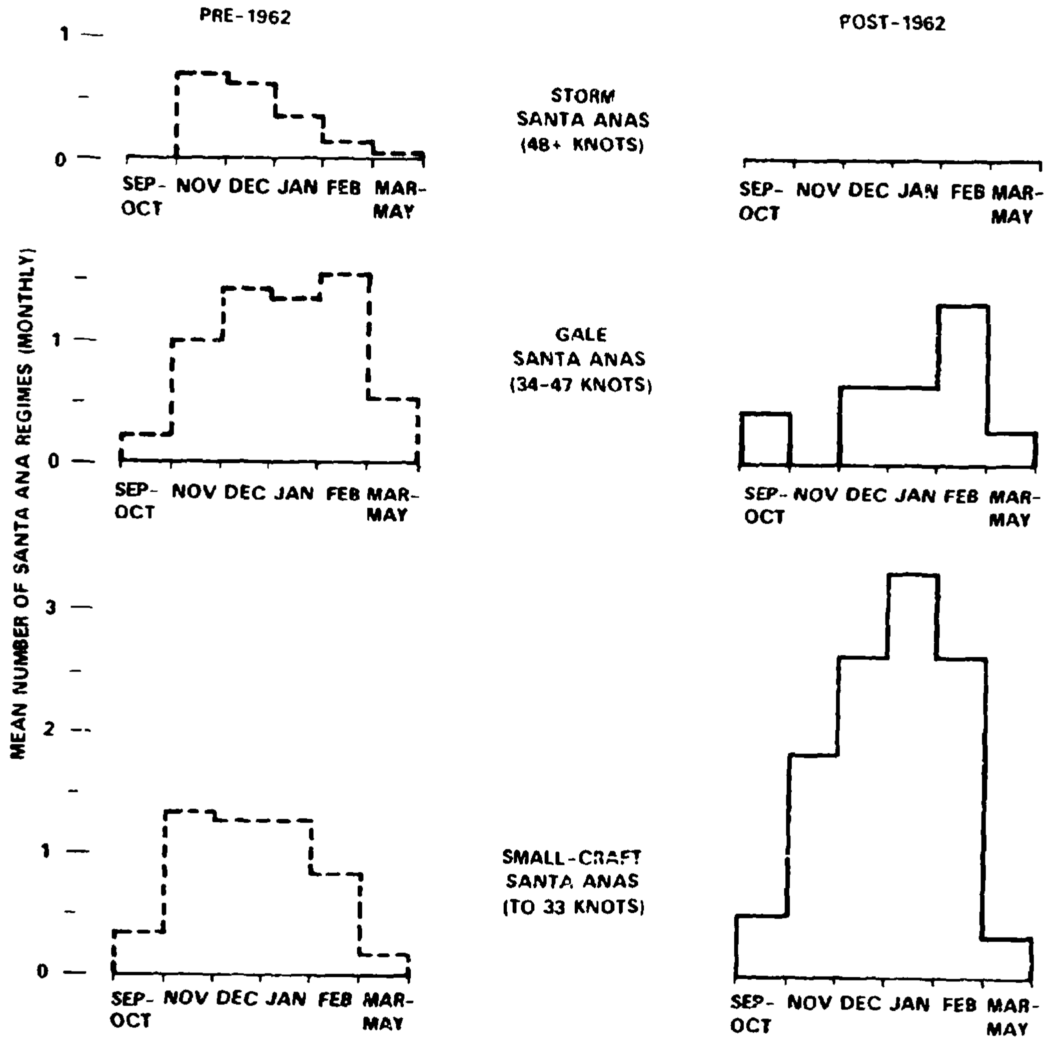


Figure 5-8. Monthly Mean Occurrence of Santa Ana Regimes With Maximum Gusts in Storm, Gale, and Small-Craft Wind-Warning Ranges. (Reference 37.)

most often occur on the first Burst. This is important because it means that the probability of wind warnings being required decreases with each succeeding Burst and the forecaster can generally expect the worst operational conditions on the first day of a Santa Ana, with slightly improving conditions on following days.

To forecast the times of onset and end of Santa Anas is operationally very important, as is forecasting the time of strongest winds. Based on the same statistics for a 20-year period (figure 5-9), both the maximum sustained wind and the maximum gust occur most frequently during mid- and late-morning hours with a secondary peak at night. Santa Ana winds of maximum strength almost never occur in late afternoon or early evening, largely because of the opposing effects of the diurnal sea breeze. When compared with figure 5-4, it appears that peak Santa Ana winds most frequently occur only a few hours before northeasterlies switch to onshore sea breezes.

One further piece of information about Santa Ana windspeeds should be applied by the forecaster in estimating the effects of any particular Santa Ana situation. That is the greater likelihood of experiencing very strong Santa Ana winds in the midseason months of November, December, and January. This is probably due to the great strength of the upper westerlies during these months, the relative weakness of the offshore Pacific High with resultant diminished

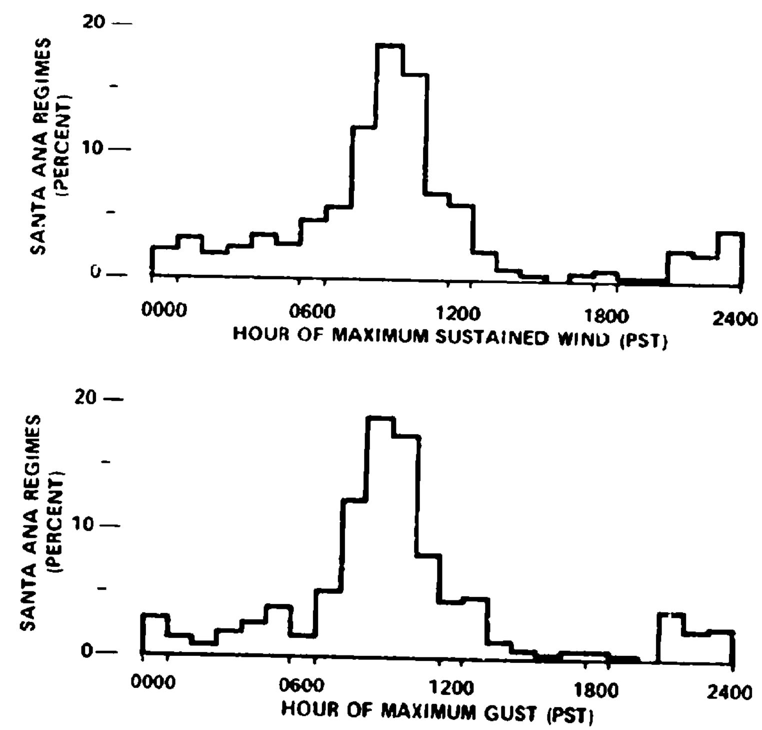


Figure 5-9. Hours of Maximum Sustained Windspeeds and Maximum Gusts Recorded During Santa Ana Regimes at Point Mugu. (Reference 37.)

support for the sea breeze, and the intense cooling of air over the Great Basin because of long nights.

Gustiness and Turbulence

One of the important and distinguishing characteristics of Santa Ana winds is their gustiness.

Rarely does the wind exhibit an evenness or constancy of speed; rather, it almost always shows large fluctuations about a mean.

The variability and gustiness of winds are noted on official observations only when they become important in their effects. According to United States weather observing practice (reference 6), this occurs when the peak windspeed reaches at least 16 knots and the variation in windspeed between the peaks and lulls is at least 9 knots. These conditions are nearly always met during Santa Anas at Point Mugu.

Operationally, the effect of gustiness is very important as a producer of aircraft turbulence at low levels during approaches and takeoffs, and in high speeds for the potential to produce damage and vibration in aircraft and tracking instrumentation. For these reasons, it is useful to be able to estimate gust intensity or a given forecast Santa Ana intensity or windspeed. Such an estimate has been derived by use of data from all Point Mugu Santa Anas of recent years (reference 37). The resulting "gust factor" (ratio of maximum Santa Ana gust to maximum Santa Ana sustained wind) has been found to be numerically equal to 1.6. This means that the maximum gust during a Santa Ana can be expected to be roughly 1.6 times as strong as the maximum sustained wind speed.

Occasionally, there are Santa Anas which are particularly gusty, as was the Santa Ana of 19 February 1970, ... the only "storm" Santa Ana on record in recent years. On that day, the 1057 PST observation showed northeast winds at 28 knots with gusts to 49 knots, ... an *instantaneous* gust factor of 1.75.

Wind Shear

Another feature of Santa Anas that is related to gustiness and aircraft turbulence is wind shear. Some change in direction and speed of the wind with height is normal almost everywhere, but during Santa Anas at Point Mugu, wind shear often becomes quite pronounced. When northeast winds occur at the surface, the most common cause of strong wind shear in the lowest few thousand feet is that northeasterlies increase in speed with increasing height. As was pointed out earlier, pre-1962 Santa Ana winds averaged about 5 knots stronger than winds since that time. Since the earlier set of data was also measured about 100 feet above the surface, the difference in speeds may indicate low level wind shear in Santa Anas. Comparison of the two sets of data for Santa Ana winds provides one further item for speculation. Based on pre-1962 data, November shows a maximum in windspeeds; for the later data period, the same month shows a distinct minimum of speeds. These differences could reflect short-period climatological changes or too small a data sample. It could also reflect, however, real month-to-month differences in vertical wind shear with shears being strongest in Novemb .

The most pronounced cases of wind shear and turbulence occur when sea breezes alter the surface flow while the northeast flow above the surface remains unchanged. Thus at times, Point Mugu may record south or west winds up to 15 knots while winds on Laguna Peak may be from the northeast at 35 knots. An example of this phenomenon is illustrated in figure 5-10 which shows Laguna Peak winds from the northeast on 16 March 1970 while Point Mugu surface winds abruptly change from northeast to south. Figure 5-11 is a photograph taken at about 0800 PST by the Point Mugu Photo/Graphics Department. Looking east-southeast toward Laguna Peak, it shows fog and low stratus moving over part of the base with onshore winds, while clear and dry Santa Ana conditions prevail just above the surface. Comparative observations are shown for Point Mugu and Laguna Peak.

Relation Between Santa Ana Intensities at Point Mugu and at Laguna Peak

The following approximate maximum windspeeds can be expected to occur at Laguna Peak for the appropriate intensity of Santa Ana winds at the surface:

Strength of Maximum Gusts at Point Mugu (Knots)	Maximum Sustained Windspeed at Laguna Peak (Knots)	Maximum Gusts at Laguna Peak (Knots)
Normal (small craft) to 33	25	40
Strong (gale) 34 to 47	35	55
Very Strong (storm) 48 or over	45 or over	65 or over

Correlations Between Surface and Upper Air Winds

Many local rules of thumb passed along over the years attempt to relate the strength of Santa Ana winds at Point Mugu with direction and with speed of winds aloft. Some of these ideas were presented earlier under the topic "Upper Winds." Based on statistics compiled in reference 37, a trend of particular interest to the forecaster, but of only limited help, becomes apparent: stronger surface gusts tend to accompany stronger easterlies aloft.

FIGURE 5-10

PMR MEASUREMENTS

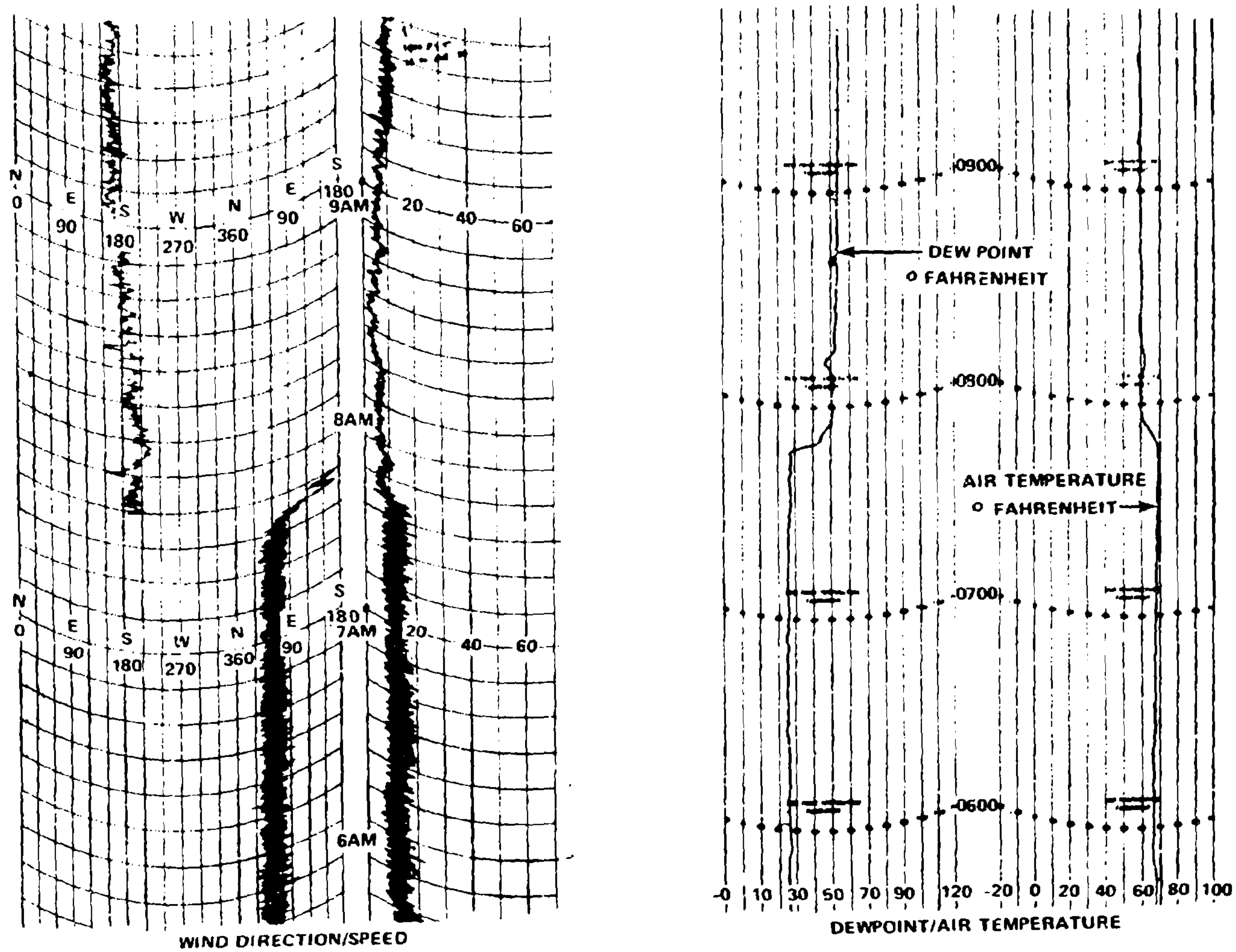
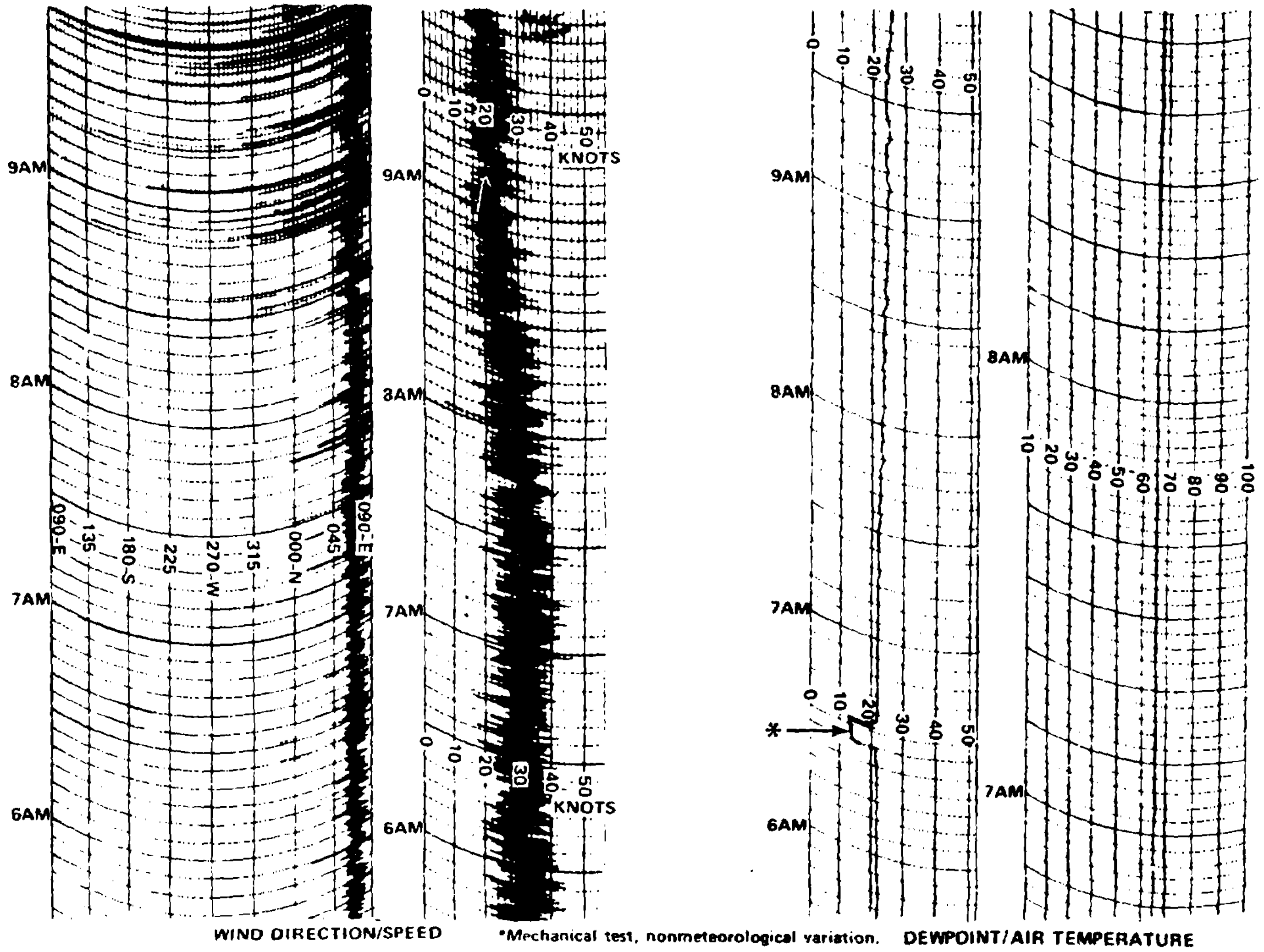


Figure 5-10. Vertical Wind Shears and Variations of Temperature and Dewpoint During Santa Ana of 16 March 1970.

LAGUNA PEAK MEASUREMENTS



*Mechanical test, nonmeteorological variation.

Figure 5-10. Concluded.

FIGURE 5-11

Time PST	Point Mugu Observations Sky	T, T_d	Wind	Laguna Peak Observations T, T_d	Wind
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 5-11 Santa Ana Eroding Top of Advancing Wall of Stratus, 0600, 16 March 1970.

More recent studies on the correlation of surface winds at Point Mugu to winds near the 3,000-foot level at Vandenberg AFB reveal some additional interesting and useful relations (reference 40). For moderate or strong 3,000-foot winds (≥18 knots) at Vandenberg AFB, east winds there are associated with moderate or strong surface northeasterlies at Point Mugu all day, and both southeast and south Vandenberg winds are associated with significant or resultant northeasterlies at Point Mugu (figure 5-12). Therefore, if morning soundings show that at 1200Z, 3,000-foot winds at Vandenberg AFB are strong and from the east or southeast, a forecast of Santa Ana or other northeast winds at Point Mugu is warranted.

Visibility

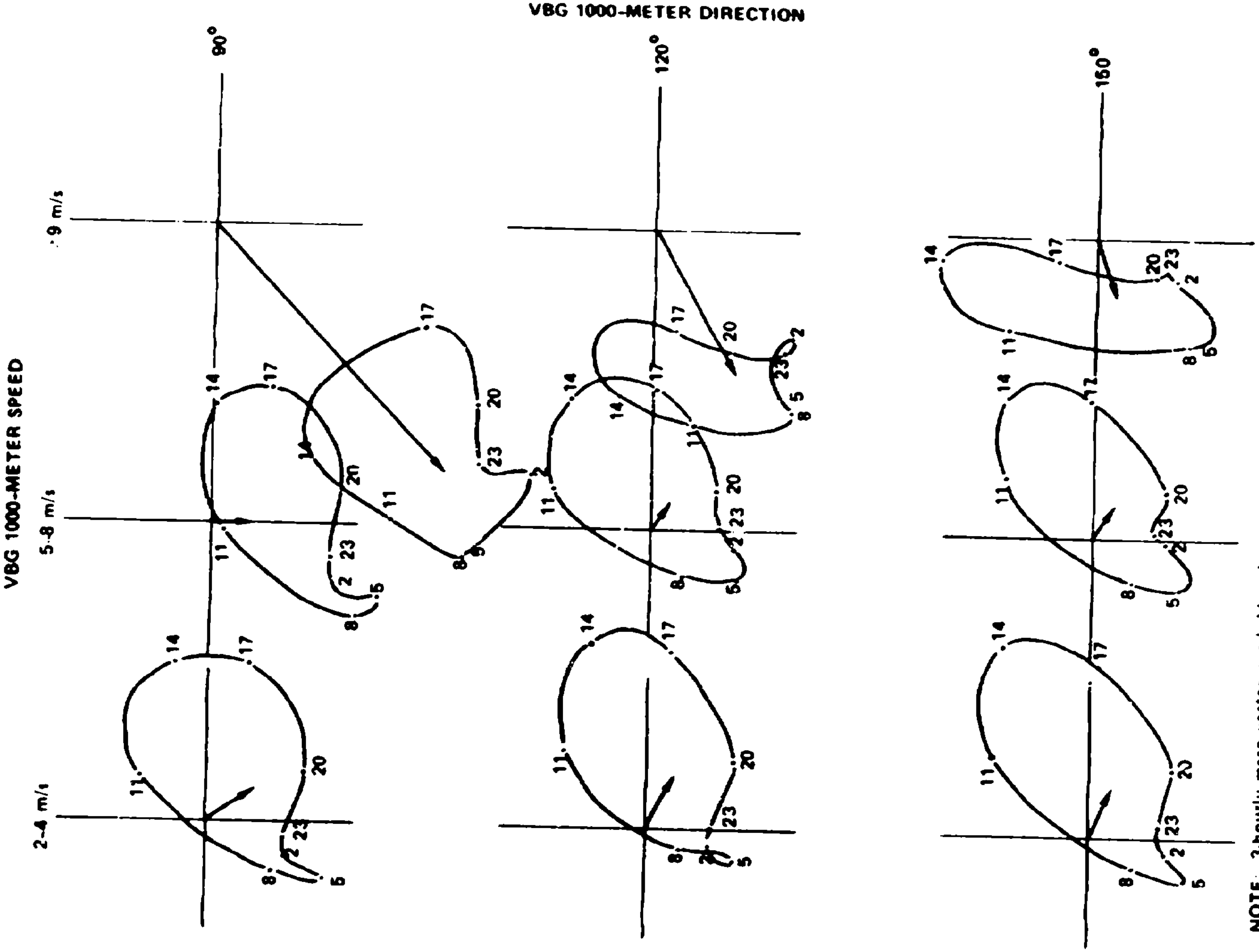
The effects of Santa Anas on visibility are complicated and at times contradictory. When winds are not too strong, or when the land is moist from recent rain, visibilities are typically excellent because of lack of pollution, marine particles, and dust. Under these conditions, it is sometimes possible in coastal southern California to see mountains 100 miles away; mountains 50 miles distant are commonly visible. On the other hand, when winds are particularly strong and nearby fields are dry, great quantities of blowing dust and sand may severely restrict local visibility. For instance, during the very strong Santa Ana of November 1957, visibilities at Point Mugu were reported as low as one-quarter of a mile in blowing dust. Generally, however, at the coast where fog, haze, and pollution are frequent, the clear air of Santa Anas is a welcome relief.

Smog and fog never occur while Santa Ana winds are actually blowing at the surface since smog and fog are observed in the marine air that is displaced by the dry offshore winds. However, before Santa Ana onset or just after ending--and sometimes between individual Santa Ana Bursts--smog and fog may be particularly dense because both pollutants and moisture are confined to a marine layer that is unusually shallow and which is frequently capped by a strong inversion. This has been observed not only locally but even as far down the coast as San Diego, (reference 41). It is not rare for visibilities to drop to zero when such a polluted marine layer cools to the saturation point during nighttime hours. When such dense fog occurs, Santa Ana winds may be blowing aloft at Laguna Peak and a few miles inland at the surface.

Sky Conditions

Sky conditions during a Santa Ana are usually clear and bright because of the subsidence and dryness of the air, and as a general rule, a forecaster

FIGURE 5-12



NOTE: 3-hourly mean vector winds blow from orig 1 *toward* points on curves, labeled with center hour (PST) of time category.
Axes of individual diagrams are 5 knots in length from origin to end. Direction categories are 30° wide, center direction indicated.
Daily resultant mean vector winds shown by short arrows.

Figure 5-12. Diurnal Mean Vector Surface Wind at Point Mugu as a Function of Reference Wind Direction and Speed, All Seasons, 1949 - 1964. (From reference 40.)

expecting a Santa Ana should forecast such sky conditions. There are occasional exceptions, however, such as the wet and unstable "pseudo" Santa Anas to be discussed under "Special Cases of Santa Ana-Like Patterns" and also the high jet-stream cirrus that is sometimes associated with strong winds aloft (figure 5-13). These clouds seldom interfere with the incoming daytime insolation unless appreciable overrunning of warmer moist air is occurring at mid and upper levels of the troposphere. If such appreciable overrunning does occur, as when there is a developing wave and a deep trough not too far offshore, overcasts thick enough to produce sprinkles may result even while true Santa Ana winds are blowing at the surface. These occurrences are, however, rare.

As for low clouds, the presence of fog and stratus is restricted almost entirely to the very shallow marine layer present just before and after Santa Ana Regimes, as shown in figure 5-11 and discussed under "Visibility." Sea breezes which occur between Santa Ana Bursts are usually modified Santa Ana air and are too dry, clean, and warm to support stratus.

A "weather sign" sometimes used to point out an impending Santa Ana is a very blue sky as one looks up, even though horizontal visibility may be poor close to the ground. This implies that some mechanism is restricting the marine layer to a very shallow depth while producing very transparent air above. Such a mechanism is the local and large-scale subsidence of clear, dry, unpolluted desert air characteristic of Santa Anas. Until the winds actually reach the surface, this condition is sometimes called a "high foehn" (reference 6).

Temperatures

The hottest temperatures recorded at Point Mugu and throughout coastal southern California have occurred during Santa Anas. There are, however, enough cases of cool and even cold Santa Anas to warrant a more detailed look at temperature characteristics. Statistical studies of Santa Anas for 21 years at Point Mugu are again the basis for the following discussion on Santa Ana temperatures (reference 37).

Seasonal Variations of Warmth

The maximum temperature reached is one way of judging the warmth of a particular Santa Ana, but an equally valid approach is to describe the maximum temperature relative to the normal maximum for that time of the year. We should expect spring and fall Santa Anas to be warmer on the average than those which occur in winter due to the normal annual temperature cycle, but it is necessary to look further to determine whether a Santa Ana brings near normal temperatures or much warmer than normal temperatures.

FIGURE 5-13

Figure 5-13. Jet Stream Cirrus at End of Santa Ana, Nimbus 3 APT, 1805-1827 Z, 3 February 1970.

The curves for both normal and for Santa Ana maximum temperatures as a function of time of year are presented in figure 5-14. A seasonal dependency is apparent for both, and even though they are in phase, the difference between the two is not constant. Thus spring and fall Santa Anas are warmer than winter Santa Anas not only in actual temperatures but also in relative warmth. Santa Ana maximum temperatures average 16 degrees warmer than normal in September and October, 22 degrees warmer in April and May, but only 8 degrees warmer in February.

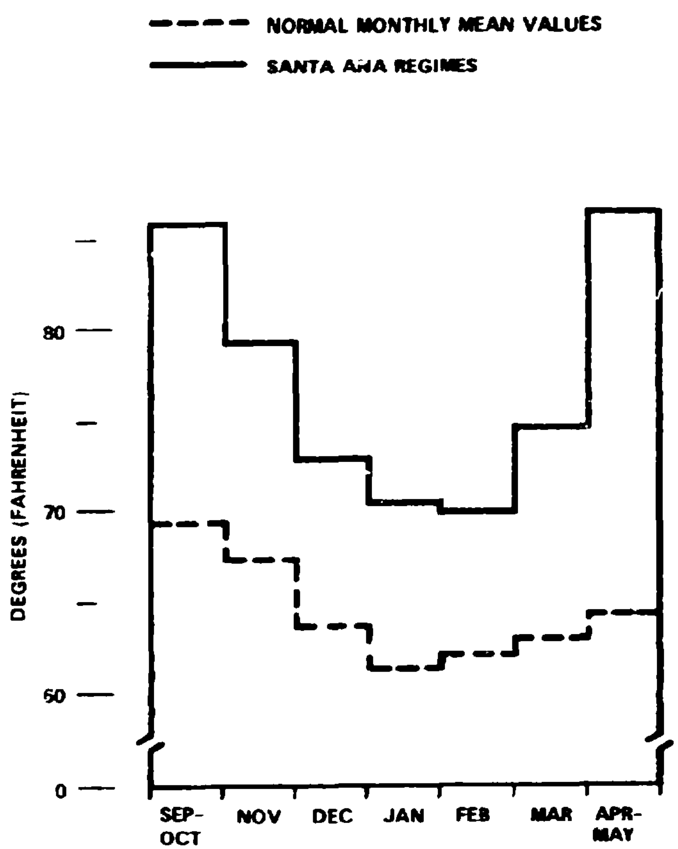
The frequency of very hot Santa Anas is important because very hot runways drastically reduce the efficiency of jet engines. For this purpose, the frequency of days with maximum temperatures of 90 degrees or above were considered as "very hot." Of the 53 days of 90°+ temperatures from 1947 through 1971, over 80% were associated with Santa Anas, including the all-time record 104° reached on 6 Oct 71. Figure 5-15 shows the frequency of 90°+ days in 10-day periods through 1969. It is apparent that the majority of such cases occur in the fall; far fewer occur in spring. None occur in winter and virtually none occur in summer, either. (The relatively few hot days that did occur in summer were not associated with Santa Ana winds at Point Mugu although the overall synoptic pattern may have been similar).

Several reasons seem likely for such a strong tendency for hot Santa Anas to occur in early fall. First of all, Santa Anas are more frequent in fall than in spring because the Pacific High is weaker. In addition, because of the lag in seasonal heating, the atmosphere on the average is warmer in early fall than it is in spring. Related to this seasonal difference is a possible tendency--on the average--at our latitude for larger amplitude waves in fall than in spring when strong zonal westerlies aloft are frequent. Such large-amplitude waves in fall would tend to bring more extreme differences in weather between ridges and troughs. Preliminary investigations have been made to determine if there is any correlation between the occurrence of heat waves in the fall and heavy mid-November rains (the "November anomaly") (reference 42) since these rains also appear to be a frequently observed characteristic of the fall season in southern California. A very qualitative relationship appears to have held during the 1960s for the hottest falls and wettest mid-Novembers.

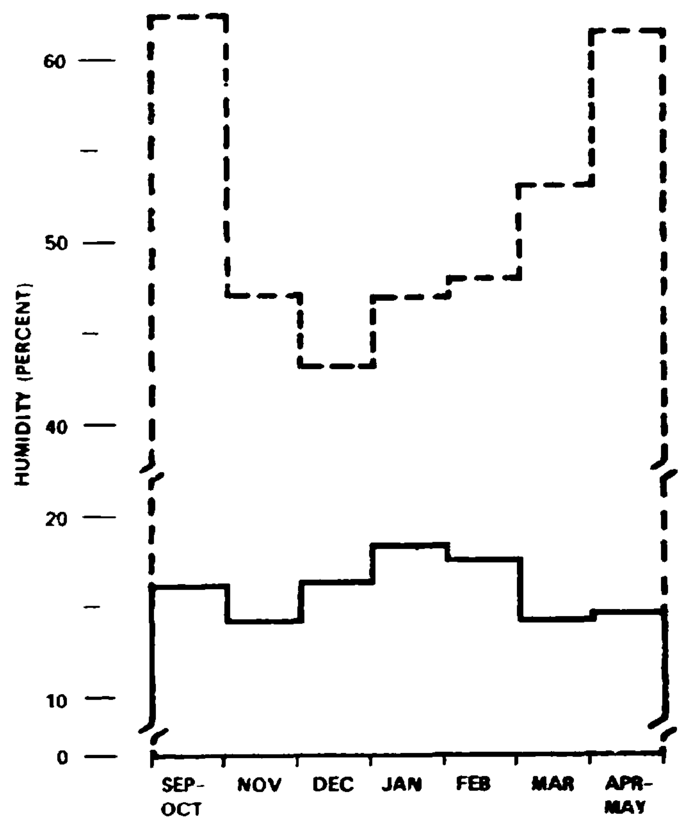
Warm and Cold Santa Anas

Another interesting feature of Santa Anas is that there appears to be a tendency for a basic separation into either "cold" or "warm" Santa Anas--as evidenced by a bimodal frequency distribution of Santa Ana temperatures, reference 37--rather than a continuous gradation from one to the other. This separation does not appear to be due to seasonal differences, but two possible reasons can be suggested. First, it could be due to temperature differences between nighttime and daytime Santa Anas. Second and more likely, it

FIGURE 5-14



(a) Mean Maximum Temperatures.



(b) Mean Minimum Relative Humidities.

Figure 5-14. Monthly Mean Maximum Temperatures and Minimum Relative Humidities. (Reference 37.)

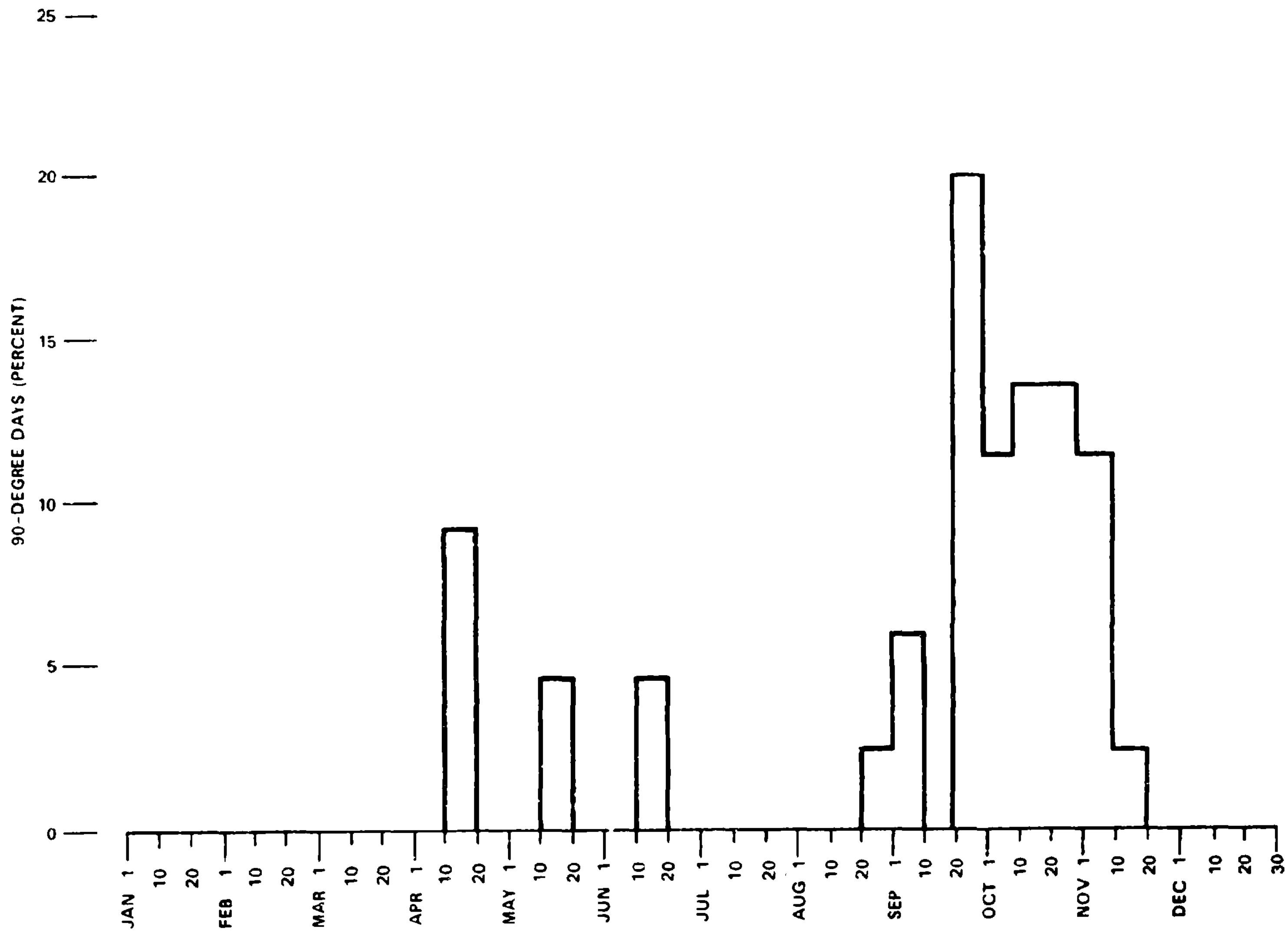


Figure 5-15. Frequency of 90-Degree Days From 1947 to 1969. (Total of 44 days.)

could be due to differences in air mass temperatures and the amplitude troughs and ridges aloft. Such synoptic differences probably also determine whether subsidence occurs from high levels or just from shallow levels over nearby terrain. Certainly an important factor in all these mechanisms is the proximity of Point Mugu to the ridge or downstream trough aloft. Santa Ana winds will be colder if Point Mugu is closer to the downstream trough than if the ridge were nearly overhead. Santa Anas would likely have more "normal" temperatures if the local area were located somewhere in between.

Figure 5-16 shows the cumulative frequencies of Santa Ana maximum temperatures. If the coldest third are arbitrarily designated cold Santa Anas, the middle third normal Santa Anas, and the warmest third hot Santa Anas, some useful guides and classifications are obtained as follows:

	Maximum temperature (°F)	Maximum temperature relative to monthly normal maximum temperature (°F)
Cold Santa Anas	69 and below	+5 and less
Normal Santa Anas	70-79	+6 to +15
Hot Santa Anas	80 and above	+16 and more

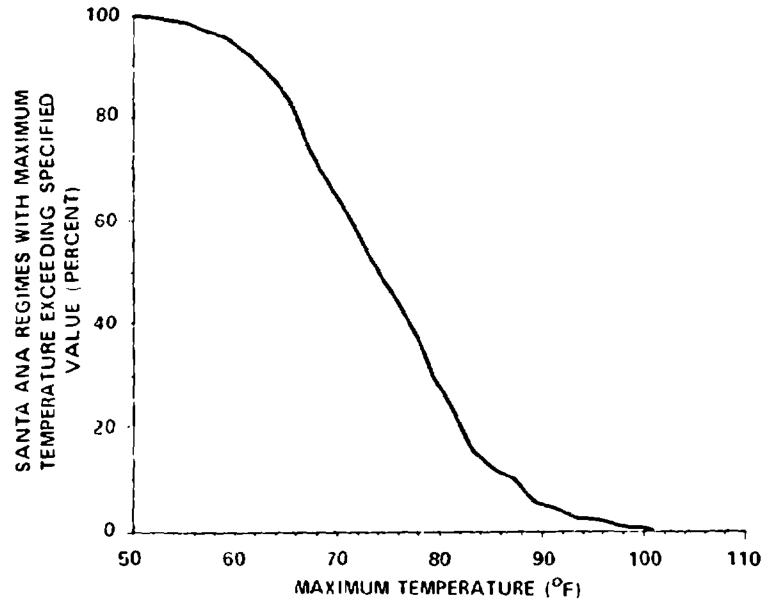
It is also useful to the forecaster making a temperature forecast to note that even a normal Santa Ana will result in daily maximum temperatures that are about 10°F warmer than the normal maximum.

Of interest as possibly the coldest Santa Ana on record at Point Mugu is the 12-15 December 1967 Santa Ana when winds blew continuously for 65 hours. Maximum temperatures for the first two complete days of Santa Ana winds were 47°F and 48°F. The third day the temperature warmed up to 57°F.

Date (All in December)	Duration (Hours)	Maximum Temperature (°F)	Minimum Temperature (°F)	Maximum Gust (Knots)
12	3	--	--	28
13	24	47	40	39
14	24	48	39	38
15	14	57	42	30

Rapid Temperature Fluctuations

One of the most dramatic features of Santa Anas in coastal southern California in addition to their unusual warmth is the magnitude and suddenness of temperature (and humidity) changes with fluctuations in the wind. The onset of Santa Ana winds usually results in very rapid increases in temperature as the cool damp marine air is suddenly displaced. The increases are probably instantaneous but thermometers characteristically have a time-lag in their response



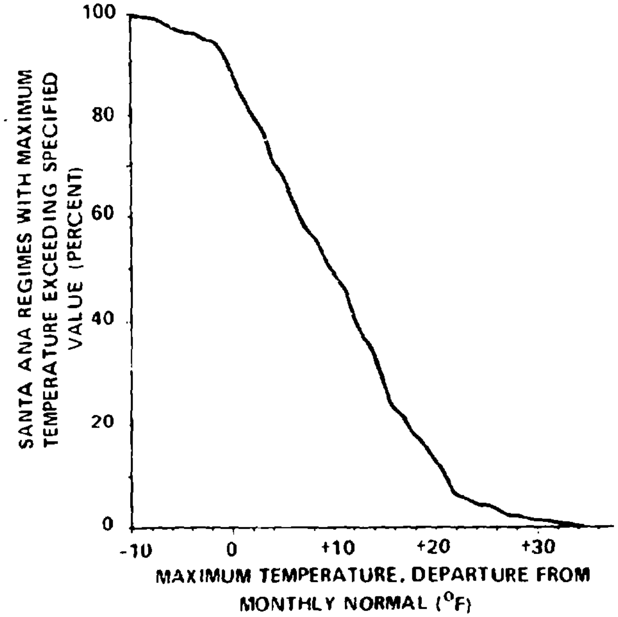


Figure 5-16. Cumulative Frequency of Santa Ana Maximum Temperatures and of Santa Ana Maximum Temperatures Relative to Monthly Normal Maximum Temperatures. (Reference 37.)

to quick temperature changes. There are just as dramatic decreases when sea breezes interrupt the offshore flow either temporarily as between Santa Ana Bursts, or permanently at the end of a Santa Ana Regime. The temperature records for Point Mugu in figure 5-10 illustrate such a sharp drop with onset of the onshore wind. Temperature changes of as much as 25° in a minute or so have been recorded. Thus even the purely diurnal variations of temperatures during a Santa Ana associated with shifts in the wind are comparable in degree to some of the strongest frontal passages experienced in the eastern and midwestern states. Moreover, such sharp temperature changes may occur several times within a single 24-hour period, with each shift in the local wind from onshore to offshore and back again. This becomes even more significant when one considers that the normal annual range of mean daily temperature at Point Mugu varies by only 11.5°F, from 64.0° in August to 52.2° in January, (reference 2).

Forecasting Maximum and Minimum Temperatures

As can be seen from the above discussion, temperatures day or night during a Santa Ana Regime depend largely on the direction and speed of the surface wind at a particular time. If northeast Santa Ana winds blew continuously day and night without intermission, a daily range of about 20° can be expected because of the diurnal heating cycle. Minimum temperatures under these conditions are often well above normal, particularly during mid-winter. Should the wind stop blowing during the night even for only a fraction of an hour, rapid loss of heat to space in the clear dry air can result in very cold temperatures at the surface, so that it is possible to set both record maximum and record minimum temperatures on the same day with a Santa Ana. An example of this occurred on 22 September 1968, one of the two summertime Santa Anas on record. On that day, a record minimum of 44° was set in the early morning during a very light offshore drift of 4 knots. By midday under bright sunshine and with northeast winds gusting to 19 knots, a record maximum of 90° was recorded. Sometimes, Santa Ana winds will begin blowing around sunrise but will only last for about 2 hours. Under these conditions, daily maximum temperatures may occur very early in the morning just before the sea breeze sets in.

The forecasting of daily maximum temperatures at Point Mugu has always been a rather difficult task due to proximity of the station to the cooler ocean waters. During Santa Ana conditions, the task is particularly difficult because of the relatively large number of important factors which must be considered such as duration of winds and their direction, initial temperatures over the desert and plateau areas, amount of daily heating due to solar insolation, trends of air mass temperature, and such local factors as sky obscuration by dust or high clouds. There are presently no available techniques which permit the forecaster to consider many of the factors mentioned above and calculate a single likely maximum temperature. Current methods are based largely on subjective feelings and consensus, together with the other general guides for temperature trend mentioned herein and in reference 37. To more quickly and objectively forecast Point Mugu's maximum temperature during Santa Anas, Geophysics Division personnel are developing an empirical equation based on the most important or critical factors. This formula, an equation, is at present tentative and its ability to verify has not been sufficiently tested to warrant its inclusion in this handbook. When a revised version has demonstrated its usefulness through verification, it will be incorporated into the next revision of this handbook.

The forecasting of daily minimum temperatures at Point Mugu is even more difficult under Santa Ana conditions since the temperature depends so heavily on the windspeed and direction as well as on temperatures aloft, nocturanal inversions, etc. Thus, an error of 5 or 10 knots in the forecast windspeed can result in a difference of 20° in the minimum temperature, --far exceeding the "normal" or typical range of minimum temperatures on either a seasonal or yearly basis.

Santa Ana Temperatures Related to Other Factors

A few more remarks concerning Santa Ana temperatures should prove useful to the forecaster in making maximum temperature forecasts. For Santa Anas with multiple Bursts, there is a tendency for each successive Burst to be slightly warmer. This may be due to an overall warming of the Great Basin air mass in traveling over terrain heated intensely by bright sunshine.

Local forecasters have at times equated the warmest Santa Anas with the strongest winds and with the weakest winds. However, there is no apparent significant relationship between temperatures and windiness (reference 37).

When the temperatures recorded are compared with the deepness or vertical depth of the offshore flow, records show that deeper Santa Anas tend to be warmer (and a little drier) than shallow Santa Anas. This is probably because surface air during a deep Santa Ana has undergone greater subsidence (reference 37).

Humidity

The dryness of Santa Ana air can be traced largely to subsidence from higher and drier levels of the atmosphere and also to the continental desert interior over which the air moves. When the air arrives at Point Mugu, dewpoint temperatures are typically in the 20s or 30s. When the air is extremely dry, dewpoints can be as low as zero or below with relative humidities less than 10%. On the other hand, if the air from the Great Basin flows over terrain that is moist from recent rains, it will result in slightly higher than normal Santa Ana dewpoints, perhaps in the 40s or low 50s.

Unlike temperature, moisture levels in Santa Ana conditions do not exhibit a pronounced dependency upon the time of day. Thus, dewpoints are usually fairly constant so long as the wind blows from the northeast. Relative humidity, on the other hand, depends heavily on the temperature and so it does vary between day and night, but even so, it generally remains less than 40% while Santa Ana winds are blowing. On a seasonal basis, minimum relative humid-

ities in Santa Anas are comparatively constant from month to month and appear to be independent of the normal annual cycle of minimum relative humidities (figure 5-14).

Figure 5-17 shows the cumulative frequency of Santa Ana minimum relative humidities. The driest third have humidities of 12% or less: the middle third include humidities of from 13 to 17%, and the wettest third have humidities of 18% or more. From this it is seen that more than half of Santa Anas reach humidities of less than 15%. Thus, the extreme dryness of the typical Santa Ana is apparent.

The only marked variations in humidity and moisture content in connection with Santa Anas occur with shifts in the wind between onshore and offshore directions. As stated before, this happens between individual Santa Ana Bursts and during onset and ending of the Regime. The change with time can be just as sudden as the change with temperature. The dewpoint trace shown previously in figure 5-10 reveals a rise in dewpoint of over 20° in a matter of minutes as the wind shifted from northeast to south. As with temperature, instrument response probably prevents the change from being instantaneous. In terms of relative humidity, there was an increase from 20% at 0700 PST to 80% at 0900 PST with most of that again occurring in a very short time. Such sudden rises in humidity are common whenever Santa Ana winds are temporarily interrupted by sea breezes and comparable falls occur when the northeast wind resumes. The same holds true at the onset and ending of almost every Santa Ana Regime.

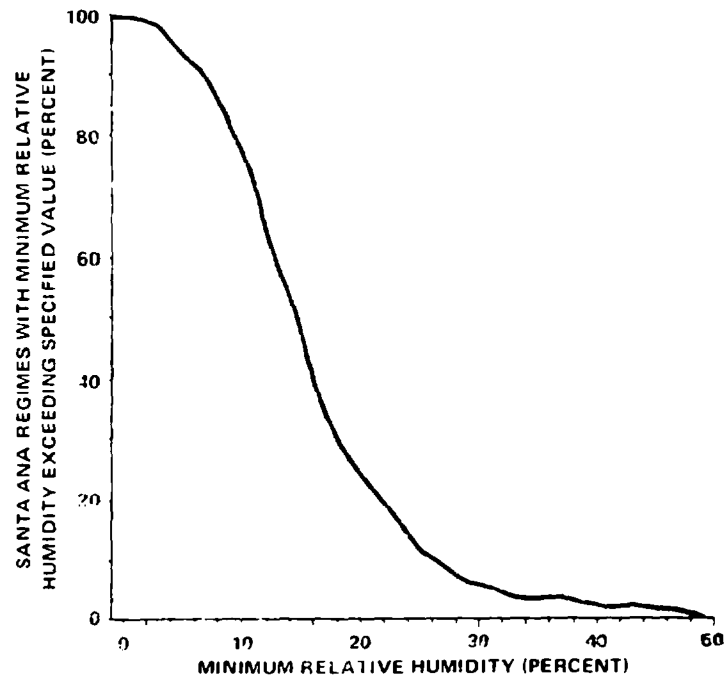


Figure 5-17. Cumulative Frequency of Santa Ana Minimum Relative Humidities. (Reference 37.)

As was stated earlier, deeper Santa Anas show a slight tendency to be warmer and drier than shallow Santa Anas.

Atmospheric Pressure

Even though Great Basin Highs produce large pressure increases over that region, Point Mugu surface pressures do not appear to exhibit any appreciable trend during Santa Anas. Whereas typical central pressures for a Basin High are near 1040 mb, Point Mugu pressures during Santa Anas average less than 1020 mb--not much higher than the 1013 mb mean during the middle of the summer stratus season and the overall annual mean surface pressure of 1015 mb. Moreover, there is considerable variation from case to case with pressures at Point Mugu ranging from a low of 1005.4 mb to a high of 1030.5 mb during individual Santa Anas of the 1969-1970 season alone. The higher Santa Ana pressures probably occur when the Pacific High offshore is still strong and connects with an even stronger Great Basin High. The lower Point Mugu pressures probably occur when low pressure systems are located not too far offshore, and weaken and displace the Pacific High while the Basin High is well established over the interior. In either case, offshore pressure gradients and not pressures themselves are responsible for the downslope dry Santa Ana winds experienced locally.

Althoug' Point Mugu pressures may vary widely from Santa .na to Santa Ana, pressures are usually fairly : .dy on any one given day, provided large changes in the synoptic pattern are not occurring near the coast. Thus, even during Santa Anas, the semi-diurnal pressure oscillation is often still discernible on the barograph trace.

Regardless of the actual pressure at Point Mugu, the over-riding consideration of importance to Santa Anas is the large scale pressure gradient or differential between P at Mugu (or coastal southern California) and the C .eat Basin.

While Bakersfield pressures might prove useful in developing forecasting aids for the occurrences of stratus, it appears that Bakersfield is much too close to Point Mugu to provide for meaningful pressure gradient calculations with respect to Santa Anas. Weather station pressures in northern Nevada generally, or even the central pressure of the Basin High, should provide better indications of the strength of the synoptic offshore pressure gradient. Based on general subjective and individual observations, it appears that pressures 10 mb or more higher than Point Mugu's are required over northern Nevada for local Santa Ana winds. For the case of the central pressure of the Basin High, a difference of about 12 mb or more appear to be required. If it is desired to use specific reporting stations, the difference between pressures at Salt Lake City (via straight line distance through Las Vegas) and that at Point Mugu should be 10 mb or more. This is based largely on observed pressures during the typical example of a Santa Ana presented in figures 5-1 through 5-2.

Many attempts have been made to relate the magnitude of these pressure gradients to the intensity of the Santa Ana, but only in a general way can we say that the larger the gradient, the stronger the winds. Some subjective and unsubstantiated relationships between the two are presented as guidelines in the "Santa Ana Forecast Guide" that appears just before the thumb rules for forecasting Santa Anas, at the end of the chapter.

Spatial Variations

In addition to diurnal changes in a Santa Ana, there are also appreciable spatial variations in wind, temperature, and humidity as well. As was stated under "Orientation of Pressure Gradient," places in the Los Angeles Basin such as Santa Monica, Malibu, and the San Fernando Valley frequently experience Santa Ana-like downslope winds while Point Mugu has a strong onshore flow, only to have the pattern reversed the following day. We often observe stronger and more persistent Santa Ana winds because of our proximity to Laguna Peak and the nearby Santa Monica mountains. The interior of the Oxnard Plain frequently has Santa Ana winds when Point Mugu observes relatively moist and cool sea breezes. Even within the confines of NAS Point Mugu, there are sometimes large variations. For instance, PMR Headquarters (Building 36) may experience northeast winds to 25 knots, temperatures in the 90s and very low humidity while the Weather Center officially reports west winds of 15 knots and moister air with temperatures in the 70s.

The primary reasons for these observed variations appear to be proximity to canyons and hills and to the sea. The first favors Santa Ana offshore winds and the second favors sea breeze flow. Thus, places in and below nearby canyons and hilly areas such as Laguna Peak can be routinely expected to have a higher incidence of hot dry winds while the beaches can be expected to have more sea breezes and fewer Santa Ana winds. This rather simple picture is complicated, however, by (1) the orientation of the large-scale pressure gradients and (2) the orientation of individual canyons. In addition, the gradual penetration and retreat of temporary, afternoon sea breezes which interrupt the Santa Ana flow cause complex convergent wind patterns, particularly in the Los Angeles Basin (reference 43). Thus, even the spatial variations of Santa Anas are not constant from hour to hour.

Fortunately, during both typical and non-typical (or pseudo) Santa Anas, there do appear to be certain "built in" controls on surface flow. For instance, almost all air arriving at Point Mugu from the north-

east appears to have first flowed through the upper Santa Clara river valley from Mint Canyon to the Saugus--Newhall areas (reference 25). This has led to the suggestion that northeasterlies in the Oxnard Plain and accompanying conditions might be called "Santa Claras," analagous to the widely accepted term "Santa Ana" (reference 37). However, air flowing through this river valley deviates much of the time before reaching the coast and arrives at Point Mugu and the coastal regions down to Santa Monica by flowing over the lower ranges or through Potrero Canyon and numerous other northeast-southwest or north-south oriented passes through the Santa Monica Mountains. That is why we observe Santa Ana winds much more frequently with our proximity to Laguna Peak than we do because of our proximity to Ventura, near the mouth of the Santa Clara River. Figure 5-18 illustrates the major paths of Santa Ana winds which reach coastal southern California.

Along the coastal stretch of California Highway 1 down to Malibu and Santa Monica, numerous consistent "micro" patterns are observable during Santa Anas. Under typical cases with appreciable subsidence from aloft, very warm, dry air usually flows to the surface at Leo Carillo Beach and Corral Beach and also near Paradise Cove in Malibu, when most other locations along the route experience afternoon sea breezes and a shallow marine layer capped by a strong inversion. Just west of Point Mugu State Beach, moderate or strong Santa Ana winds nearly always reverse direction a short distance out over the water due to eddy formation, and from the southwest and strike the coast at road level, complete with blowing spray. These and other tiny patterns built by topography into the Santa Ana picture are important for low-flying aircraft during operations.

Laguna Peak . . . an example of Spatial Variation in the Vertical

The top of Laguna Peak, by virtue of its near 1,500-foot elevation is frequently representative of the low-level flow but not of surface conditions themselves. This is particularly true of Santa Anas. Generally, winds atop Laguna Peak are stronger, begin earlier, and end later than Santa Ana winds at Point Mugu's surface instrument locations. In fact, when Santa Anas strike the area, one of the points where winds are first observed is Laguna Peak. For this reason, Laguna Peak wind observations may be used to great advantage as a short-term predictor of Santa Ana winds at Point Mugu. Another useful source of data for indications of Santa Ana onset is the wind and temperature from the National Weather Service automatic station on South Mountain in Santa Paula

FIGURE 5-18

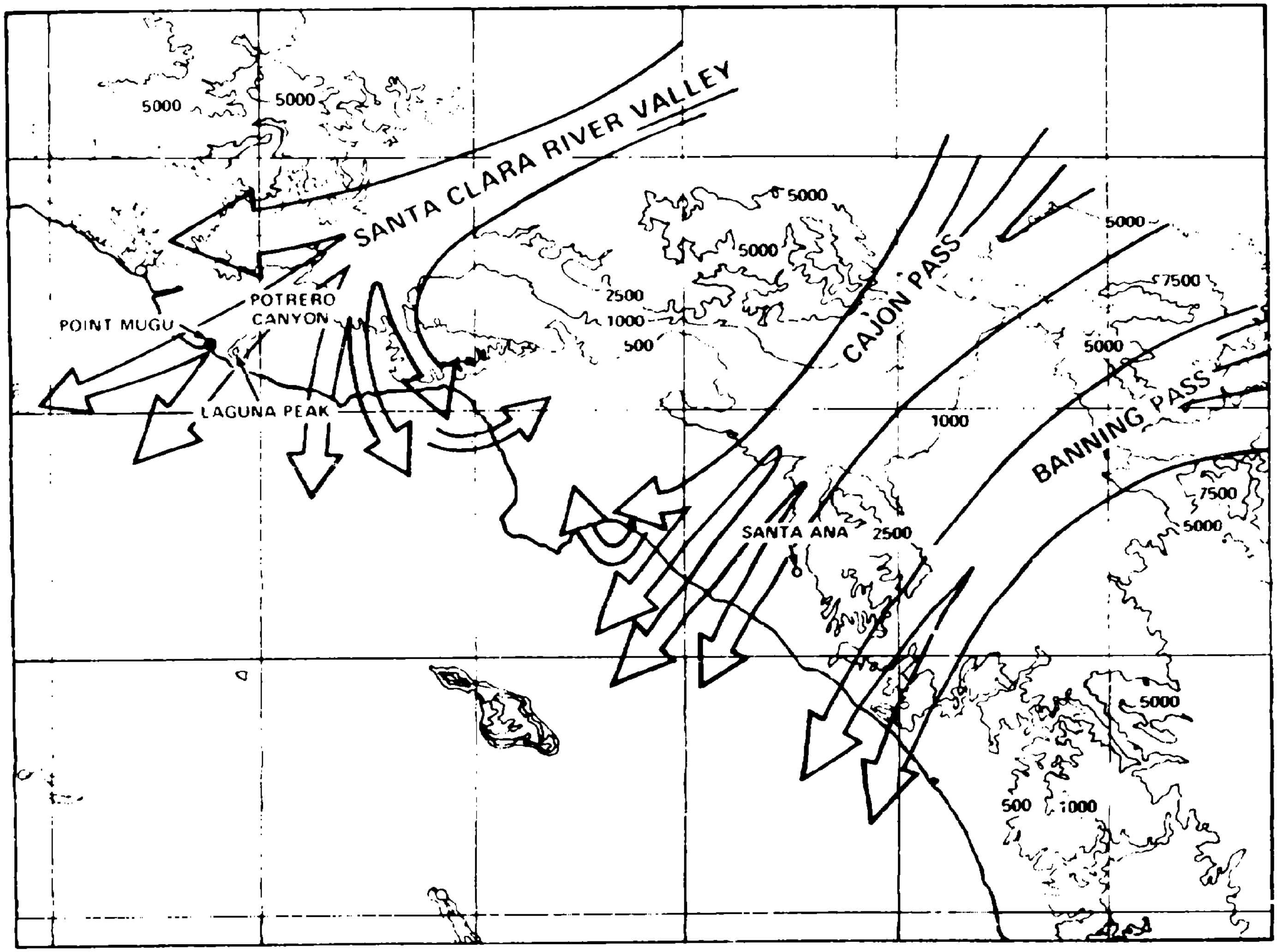


Figure 5-18. Major Paths and Regions of Santa Ana Winds That Reach Coastal Southern California.

(elevation 2,000 feet MSL, and approximately 15 miles inland from Ventura).*

There are times when incipient Santa Anas are not strong enough to erode the marine layer seaward and consequently do not reach the surface. During such situations, fog and typical marine layer conditions may persist all day at Point Mugu while dry, moderate Santa Ana conditions are observed atop Laguna Peak. Figure 5-11 showed dramatically how different weather conditions can be at these two sites under a general Santa Ana flow. Even during the typical Santa Ana day, the wind reversal to a sea breeze will occur later atop Laguna Peak than it will at the surface since the onshore flow is very shallow initially and takes time to develop sufficient depth to reach the Peak. Wind, temperature, and dewpoint recording charts for the two stations are frequently similar to the ones that have been shown in figure 5-10.

Santa Anas at San Nicolas Island

Santa Anas at SNI (San Nicolas Island) generally bring the same clear, warm, dry weather that they do at Point Mugu. Due to the elevation of the island station (564 feet), Santa Anas may occasionally blow at this remote site even though they are not being observed at Point Mugu. On the other hand, due to SNI distance from mainland topographic features which are instrumental in channeling the dry winds to the surface, Santa Ana winds at SNI are probably weaker and far less frequent than they are at Point Mugu. This view seems to be substantiated by the wind roses for both stations (reference 2). At Point Mugu, the annual wind rose shows northeast winds to be very prominent, second only to the westerly sea breezes. During the height of the Santa Ana season from November through February, northeast winds are the most prominent of all. On the other hand, wind roses for San Nicolas Island show only very minor representation of northeast winds during December and January, almost negligible when compared to the very dominating northwest winds there.

*Data for South Mountain in Santa Paula is given in code by calling (805) 525-3914 by phone. Following a brief reference tone (low pitch), the windspeed is given in miles per hour by the total number of high pitch beeps in a one-minute span of transmission. Following a brief pause, the wind direction is given 5 times (they may differ slightly) by sets of lower pitched beeps where the number of beeps in each set represents the direction as follows: 8 beeps = N, 1 = NE, 2 = E, 3 = SE, 4 = S, 5 = SW, 6 = W and 7 = NW. Last, the temperature is given by 2 sets of beeps. The first is the tens digit (7=70 etc.) and is high-pitched; the second is the ones digit (3=3) and is slightly lower. Thus a set of seven beeps followed by one of three would be 73 degrees.

Seaward Extent

Many PMR operations are conducted over the Sea Test Range and water immediately offshore. Therefore it is necessary to consider the effects of Santa Anas upon these regions. The three factors of importance are the disturbance of the sea surface itself by strong winds with consequent interference to ships and retrieval operations, the strengthening of a very low super-refractive layer (see chapter 11) which may cause anomalous propagation of ship-board radar energy, and the seaward extent of low level wind shear and turbulence which is hazardous to aircraft and may adversely affect missile performance and evaluation. Generally, the offshore winds appear to damp out the larger waves and swells resulting in small surf along the coast, and small waves but rough surfaces for some distance out to sea. If the winds are very strong and many miles out from the coast, the possibility of high waves and potentially destructive surf loom as a danger to shipping, harbors, and shore installations on the east coasts of the Channel Islands. Avalon harbor on Catalina Island is particularly vulnerable to high winds and seas from the east and suffered major damage during the strong Santa Ana of January 15-17, 1966 (reference 44). But such occurrences are rare and in the great majority of Santa Anas, fetch and duration limitations prevent appreciable buildup of seas.

The question of the seaward extent of Santa Anas is an important but largely unanswered one due to lack of data and measurements. At times it appears that the northeast winds leave the surface soon after crossing the coast; at other times the winds seem to persist at the surface for 20 miles or more. Surface measurements made at San Nicolas Island and atop other Channel Island locations are not too helpful because they do not necessarily indicate the winds at sea level since the observing stations are located at relatively high elevations. Warm dry air may easily flow over a shallow moist marine layer for a considerable distance without eroding that layer at all. Oceanographic buoys to be installed to the south of Point Mugu will transmit wind data back to the Weather Center and should prove useful in the future in determining the seaward extent of Santa Anas.

Occasionally, some useful information is obtained from "indirect" measurements of the state of the sea and lowest layers of the atmosphere. The ESSA-6 satellite (figure 4-15) on 9 April 1968 captured a picture of what is believed to be the seaward extent of a Santa Ana on that day. With sunglint illuminating the waters around Point Conception and off southern California, a dark region extending about 50 to 100 miles to sea is very prominent and is believed to be the region of water over which Santa Ana winds are blowing. Whether it is due to a calmer subdued water

surface in an otherwise west-wind-roughened sea, or a northeast-wind-roughened sea within an otherwise calmer and normal sea is open to conjecture. The point remains that the differences in color are because differences in specular reflection of sunlight from the surface of the ocean presumably due to wind differences. Moderate Santa Ana winds were actually observed at the coast that day from Point Mugu east to near Santa Monica, the same stretch of coast that defines the borders of the dark region in the satellite photograph.

SPECIAL CASES OF SANTA ANA-LIKE PATTERNS

As stated in previous sections, the classical picture of synoptic features and events leading to Santa Ana development as represented in figures 5-1 through 5-2 is not always observed, even though Point Mugu may experience strong gusty northeast winds. In short, there are a variety of synoptic conditions resulting in northeast winds which bear at least some resemblance to a typical Santa Ana pattern but which also contain significant differences so as to make the distinction between a "real" or "pseudo" Santa Ana an interesting problem. In some cases, the weather accompanying the northeasterlies is vastly different from typical Santa Ana weather. Frequently, only very subtle changes are required in the synoptic pattern to go from typical Santa Ana conditions to "wet" and unstable *Santa Ana* conditions (or vice versa) without any appreciable change in either direction or speed of the surface northeasterlies. The most common examples of "pseudo" Santa Anas are briefly described below.

"Cyclonic" Santa Anas

When a large an altitude ridge aloft builds strongly into the Pacific Northwest but not at lower latitudes, the downstream trough sometimes becomes so sharp that a cutoff low and a pool of cold air aloft form just to the east and south of Point Mugu and southern California. When this occurs, a strong surface high is present over the Great Basin just as in ordinary Santa Anas, but a surface low also develops near the California-Arizona-Mexico border area. Thus the outflow of cold, dry air from the high is joined by a flow of cold, moist, unstable air from the low with considerable cloudiness, strong surface winds, and sometimes showers. The easterly and northeasterly surface winds experienced at Point Mugu are then caused by the combined effects of the Basin High and the surface low and are *not accompanied* by large-scale subsidence such as characterizes the typical Santa Ana. The closer the cutoff low and its surface counterpart are to Point Mugu, the more cyclonic are Point Mugu's northeasterly winds and the wetter and more unstable is the weather likely to be.

Approximately once each year, very cold Canadian arctic air is entrained into the circulation with very low freezing levels and snow in the mountains and deserts. The only three cases of snow reported at Point Mugu during the official 22 years of record occurred during such cold-low situations during Santa Ana-like northeast winds: 10-13 January '49, 28-30 January '57, and 22-23 January '62. The 1949 episode resulted in widespread snowfalls and thunderstorms over much of coastal southern California. Figures 5-19 and 5-20 show the synoptic patterns for this case at the surface and at the 500-mb level. A resemblance to the overall synoptic pattern of a typical Santa Ana is apparent. Similar patterns accompanied the snow of 1957 and 1962. In these two instances, clouds, rain and occasional snow flurries gradually diminished and eventually gave way to clear skies and apparent foehn conditions with no significant change in the strong northeasterlies which blew throughout the transition, thus illustrating the subtleness with which the synoptic pattern changes from the cyclonic Santa Ana to the true Santa Ana when the cutoff low finally drifts eastward.

There is a similar situation when the cutoff low actually forms or drifts over the waters south of Point Mugu but in these cases, surface northeasterlies may be much warmer and conditions more tropical than in the very cold cases just mentioned. Figures 5-21 and 5-22 show the synoptic patterns at the surface and at 500 mb for one of these examples. Again, the similarity to typical Santa Ana patterns is apparent, particularly at the surface. The surface map, taken right from the daily forecast sheet of 10 November 1969, is accompanied by the forecast weather for Point Mugu. The scattered showers (0.05 inch was actually recorded), the northeast winds for the morning and night hours, and the further outlook of clear, windy, and warmer illustrate the complexity of Point Mugu weather during pseudo Santa Anas and their transition to more typical ones.

On rare occasions during a real (noncyclonic) Santa Ana, overrunning of moist air from a low deepening just off the coast may result in sprinkles of rain falling through the warm, dry northeast winds at low levels.

Subsynoptic Northeast Winds

Rising pressures and a surge of modified polar air frequently follow frontal passages during the cooler winter months. Accompanied by the leading edge of a short-wave ridge aloft, the building surface high of cold air may channel air into the heads of local valleys producing canyon-intensified Santa Ana-like northeast winds at Point Mugu and the Oxnard Plain. Such pseudo Santa Anas are very localized and are often not observed elsewhere in coastal southern California. The warming and drying of air in these situations is due to descent through mountain passes and surface valleys from the (approximately) 2,500-foot elevations of the Antelope Valley and nearby high deserts and is not as great as in the classic Santa Ana when subsidence occurs from higher elevations over the Great Basin.

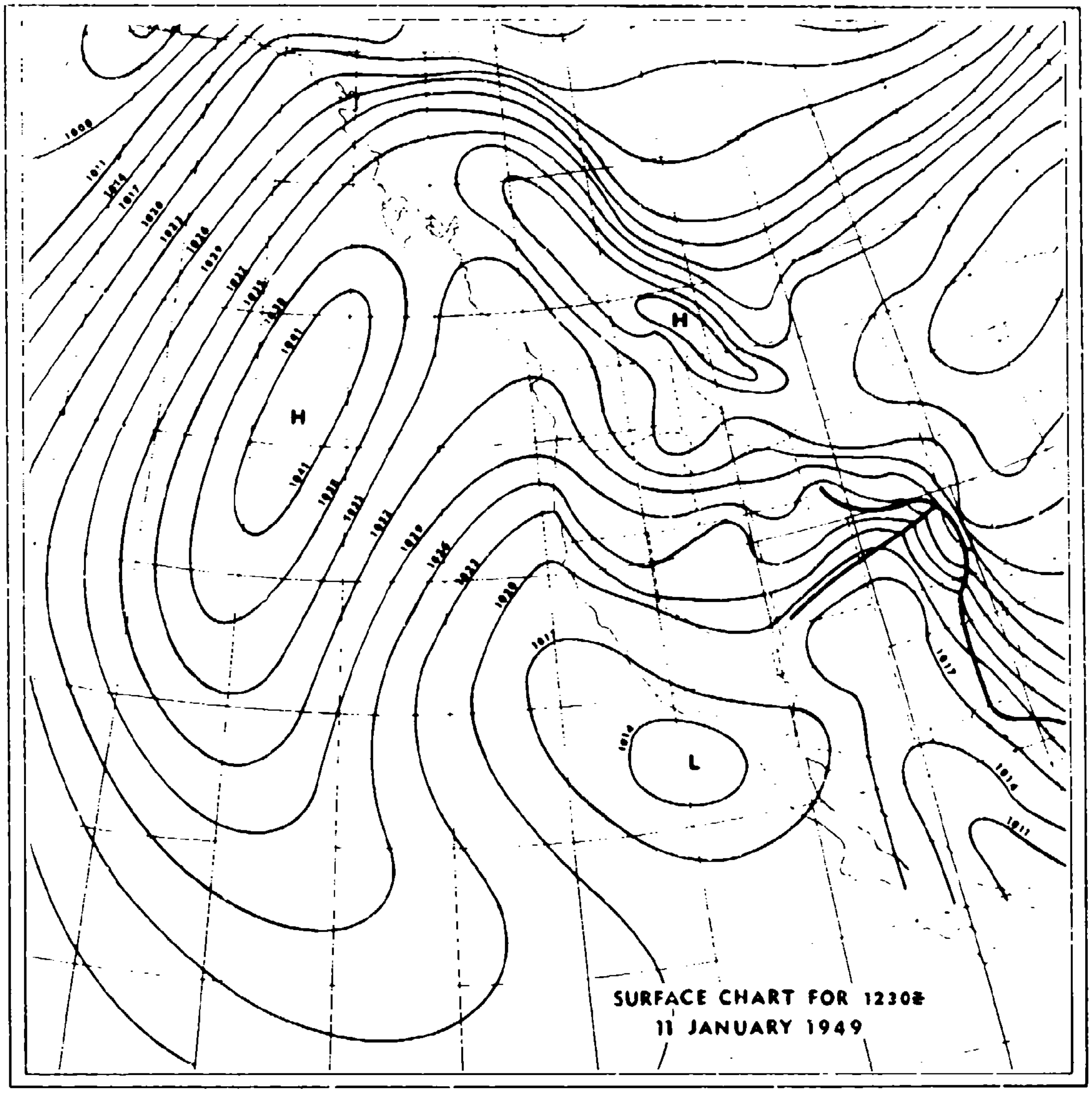


Figure 5-19. Surface Analysis During Point Mugu Snowfall of 1949.
(Courtesy National Weather Service)

FIGURE 5-19

FIGURE 5-20

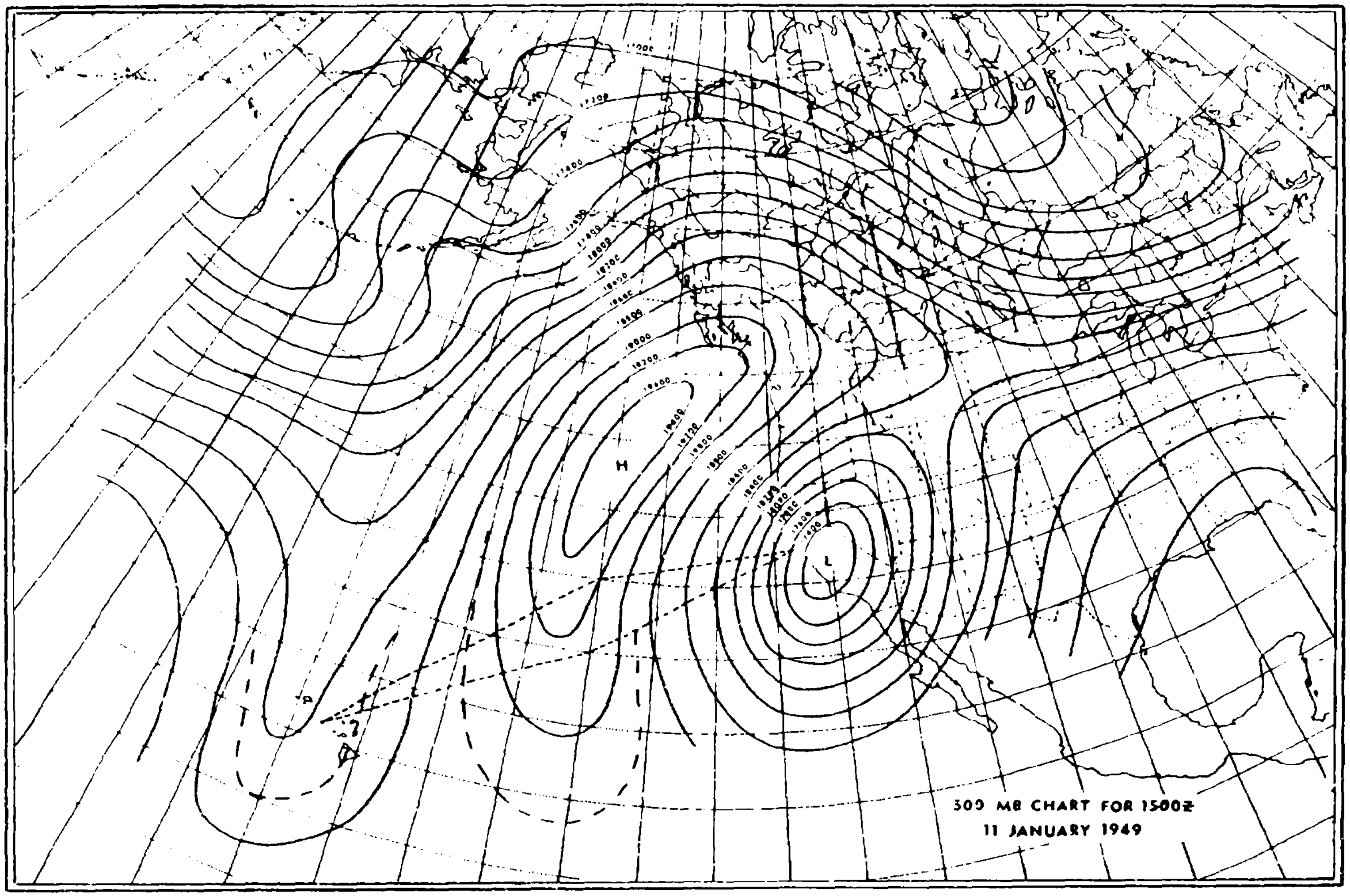


Figure 5-20. 500-Millibar Analysis During Point Mugu Snowfall of 1949. (Courtesy National Weather Service)

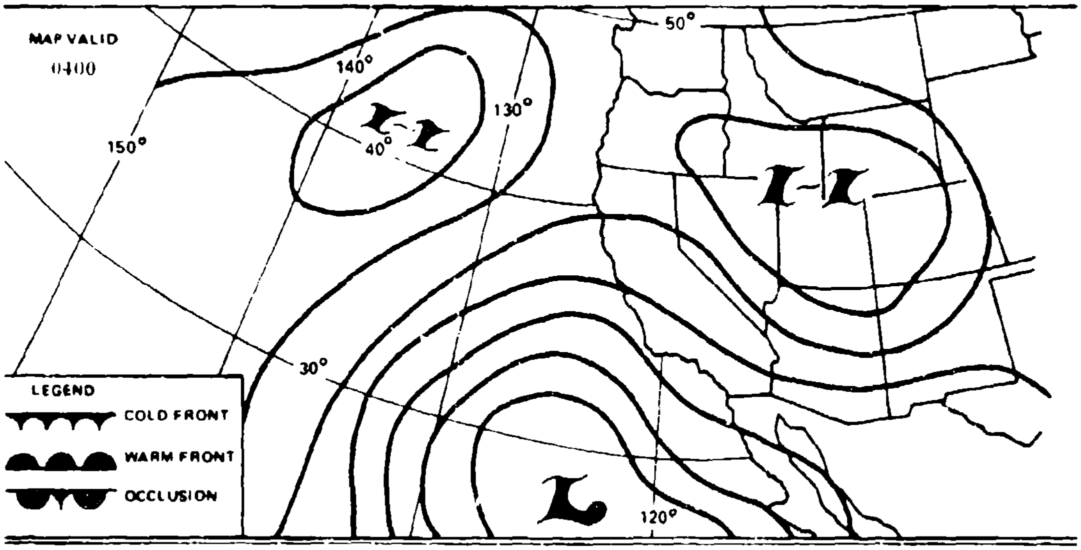
PMR WEATHER CENTER AREA FORECAST
11ND-PMR-3145/1 (REV 10-68)

All times local MONDAY
For official use only 10 NOVEMBER 1969

SUNSET TONIGHT - 1656	FREEZING LEVEL 9,200	SUNRISE TOMORROW 0625

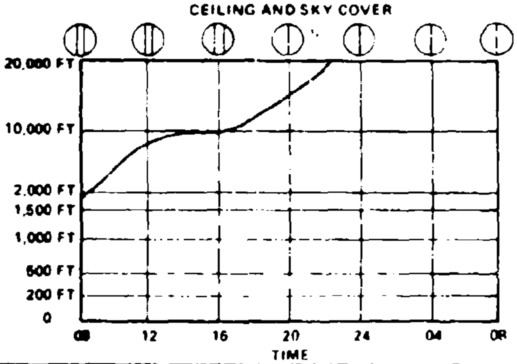
TIDES HIGH: 3.8 FEET AT 2208 10 NOV AND 6.6 FEET AT 0902 11 NOV 1969
LOW: −0.9 FEET AT 1545 10 NOV AND 2.2 FEET AT 0245 11 NOV 1969

MAP VALID 0400

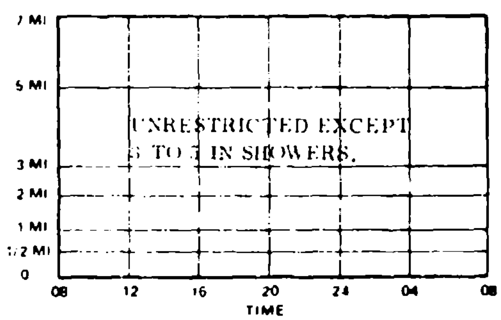


POINT MUGU FORECAST FOR PERIOD 0800 TODAY TO 0800 TOMORROW

CEILING AND SKY COVER



VISIBILITY



WEATHER SCATTERED SHOWERS DECREASING IN FREQUENCY DURING THE DAY.

WINDS NORTHEASTERLY 10 TO 15 KNOTS BECOMING W 8 TO 12 KNOTS IN THE AFTERNOON. LIGHT AND VARIABLE AFTER SUNSET AND RETURNING TO NE 10 TO 15 KNOTS WITH GUSTS TO 25 TO 30 TUESDAY MORNING. SHIFTING TO THE W 8 TO 12 IN THE AFTERNOON.

MAX TEMPERATURE TODAY - 72	MIN TEMPERATURE TONIGHT - 55
WEATHER TOMORROW PARTLY CLOUDY TO CLEAR	FURTHER OUTLOOK MOSTLY CLEAR, WINDY AND WARMER

SAN NICOLAS ISLAND SUMMARY

CLOUDY WITH LIGHT RAIN SHOWERS BECOMING PARTLY CLOUDY. CEILING 500 TO 1000 MORNING HOURS, 3000 TO 4000 DURING AFTERNOON AND EVENING. VISIBILITY 4 TO 6 MILES IN LIGHT RAIN SHOWERS AND FOG IMPROVING TO UNRESTRICTED NEAR 1100. SURFACE WINDS SOUTHERLY 10 TO 15 KNOTS

SEA SLIGHT SWELL SOUTHERLY 1 TO 3 FEET

SAN NICOLAS ISLAND UPPER WINDS

2 K	095 18	15 K	101 42	30 K	094 62	45 K	119 20
5 K	100 39	20 K	117 40	35 K	090 35	50 K	094 16
10 K	103 39	25 K	083 53	40 K	086 20	60 K	226 06

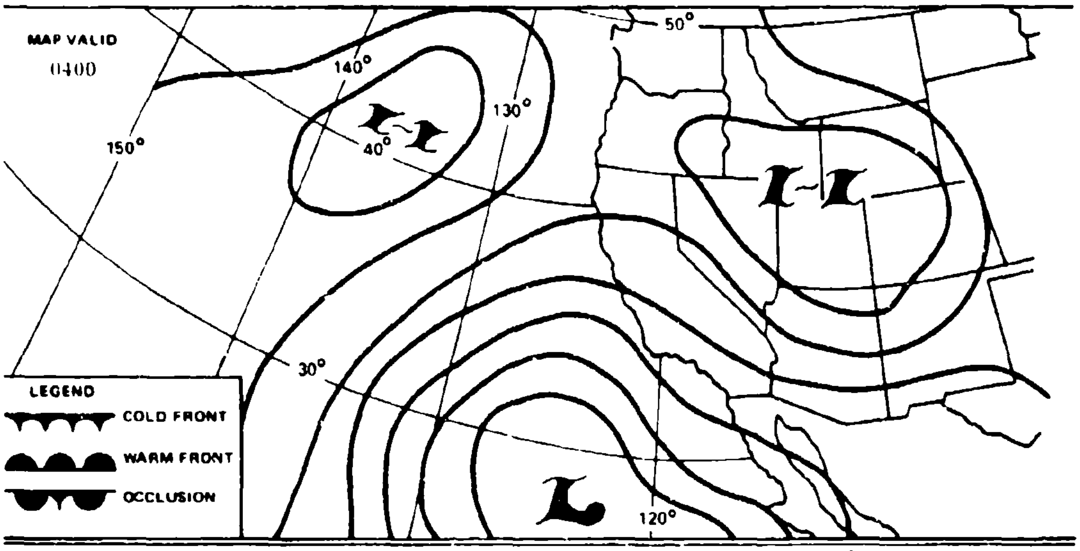
ISSUED (Weather Center Duty Officer) C M Hill LCDR C. M. HILL, USN	APPROVED (Duty Officer) CDR C. [illegible]

FIGURE

SUNSET TONIGHT - 1656	FREEZING LEVEL 9,200	SUNRISE TOMORROW 0625

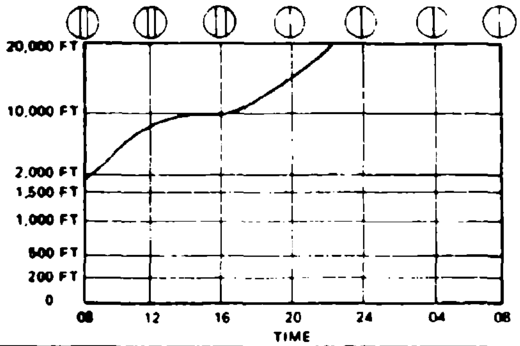
TIDES HIGH: 3.8 FEET AT 2208 10 NOV AND 6.6 FEET AT 0902 11 NOV 1969
LOW: −0.9 FEET AT 1545 10 NOV AND 2.2 FEET AT 0245 11 NOV 1969

MAP VALID 0400

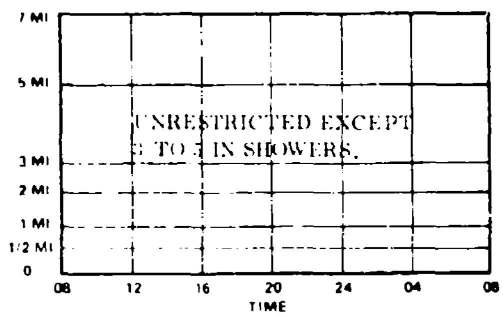


POINT MUGU FORECAST FOR PERIOD 0800 TODAY TO 0800 TOMORROW

CEILING AND SKY COVER



VISIBILITY



WEATHER SCATTERED SHOWERS DECREASING IN FREQUENCY DURING THE DAY.

WINDS NORTHEASTERLY 10 TO 15 KNOTS BECOMING W 8 TO 12 KNOTS IN THE AFTERNOON. LIGHT AND VARIABLE AFTER SUNSET AND RETURNING TO NE 10 TO 15 KNOTS WITH GUSTS TO 25 TO 30 TUESDAY MORNING. SHIFTING TO THE W 8 TO 12 IN THE AFTERNOON.

MAX TEMPERATURE TODAY - 72	MIN TEMPERATURE TONIGHT - 53
WEATHER TOMORROW PARTLY CLOUDY TO CLEAR	FURTHER OUTLOOK MOSTLY CLEAR, WINDY AND WARMER

SAN NICOLAS ISLAND SUMMARY

CLOUDY WITH LIGHT RAIN SHOWERS BECOMING PARTLY CLOUDY. CEILING 500 TO 1000 MORNING HOURS, 3000 TO 4000 DURING AFTERNOON AND EVENING. VISIBILITY 4 TO 6 MILES IN LIGHT RAIN SHOWERS AND FOG IMPROVING TO UNRESTRICTED NEAR 1100. SURFACE WINDS SOUTHERLY 10 TO 15 KNOTS.

SEA SLIGHT **SWELL** SOUTHERLY 1 TO 3 FEET

SAN NICOLAS ISLAND UPPER WINDS

2 K	095 18	15 K	161 42	30 K	094 62	45 K	119 20
5 K	100 39	20 K	117 30	35 K	090 25	50 K	091 16
10 K	103 39	25 K	083 53	40 K	080 20	60 K	226 06

ISSUED (Weather Center Duty Officer) C M Hill
LCDR C. M. HILL, USN

APPROVED (Supervisory Officer)
CDR R. C. SHERAR, USN

Figure 5-21. PMR Weather Center Forecast Sheet and Surface Analysis of 10 November 1969.

FIGURE 5-21

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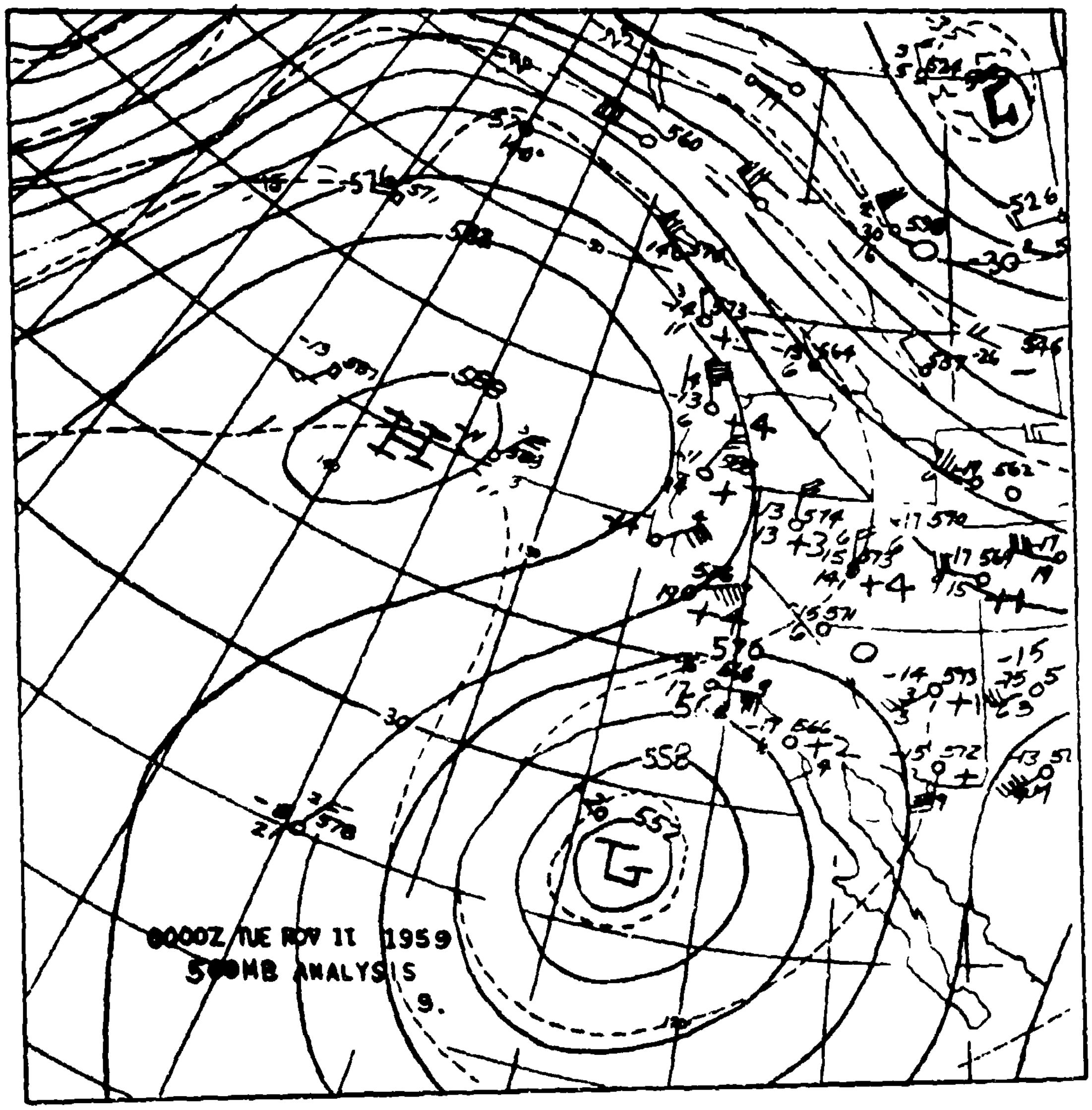

Figure 5-22. National Meteorological Center 500-Millibar Analysis of 0000 Z, 11 November 1969.

FIGURE 5-22

DURATION AND ABATEMENT

Typical Duration

Generally, Santa Anas do not end nearly as dramatically as they begin. Winds usually slacken off gradually (except between individual Bursts) and there is a general lessening of severity before the final shift to onshore flow.

Typically, Santa Ana winds blow at Point Mugu on two consecutive days, separated by an afternoon sea breeze. Thus, the most frequent total elapsed time for a Santa Ana Regime (start to finish of northeasterlies including temporary sea breezes between Bursts) is 24 to 30 hours (reference 37). Half of the Santa Anas last longer than 28 total hours and have more than 21 hours during which northeast Santa Ana winds actually blow at the surface. The longest Santa Ana on record (since the wind equipment was lowered from the hangar roof to the present runway location in 1962) was 103 hours (4 days and 7 hours) on 21-25 December 1967.

Figure 5-23 shows the seasonal distribution of Santa Ana durations based on statistics compiled over a 20-year period (from reference 37). It can be seen that Santa Anas last longer in November, December, and January than they do during other months. This is probably because those months have the shortest days (and longest nights) of the year and hence Santa Anas in those months are aided by nighttime drainage

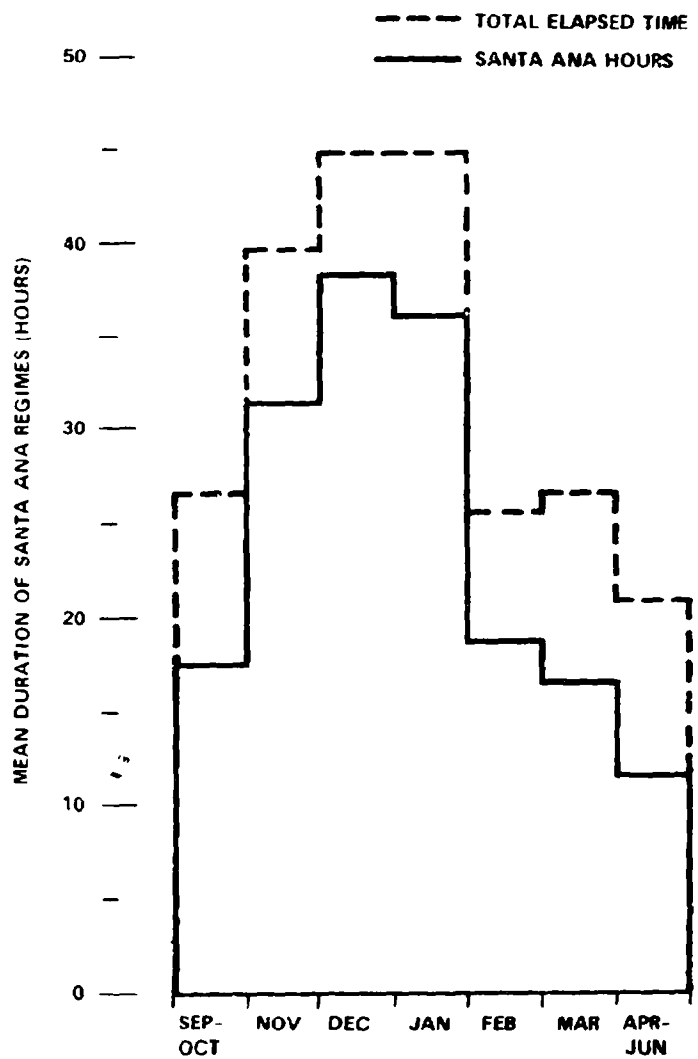

Figure 5-23. Seasonal Distribution of Santa Ana Durations. (Reference 37.)

of cold air which probably helps Santa Anas to begin earlier in the night and end later in the morning.

In terms of individual Bursts, the most frequent duration is 4 to 6 hours but one Burst (period of uninterrupted northeasterlies) has lasted for 122 hours. Generally, the first Burst of a Santa Ana is the longest with each progressive Burst getting shorter. The first Burst is also most likely to set in after sunrise, whereas the second and succeeding Bursts are more likely to set in during the evening hours. Additionally, each successive Burst tends to be weaker and warmer until the end is reached. On the average, it appears that Santa Anas that last the longest also have the strongest winds. On the other hand, when duration is compared with the depth of easterlies, no significant correlation is found. This is contrary to informal rules of thumb passed along over the years from forecaster to forecaster.

Role of Pressure Gradient and Its Orientation in Abatement

Movement and Decay of Great Basin High

When the Great Basin High begins to weaken and move eastward toward the Rocky Mountains (usually in response to the upper air pattern), the offshore pressure gradient in coastal southern California greatly relaxes and finally reverses to onshore. This results in the end of the Santa Ana and has been illustrated in figure 5-1(i). At that point, Point Mugu may lie in a general col, as shown, and thereafter the influence of the Pacific High cell becomes dominant at the surface.

Sometimes, eastward movement of the Basin High results in a southeast-northwest isobar orientation over coastal southern California. This orientation usually results in southeasterly or southerly sea breezes with continued warm temperatures when Santa Ana winds end and marine conditions return. It also often results in some of the smoggiest conditions at Point Mugu.

Heating in Interior and Establishment of Thermal Trough

When the ridge aloft begins to move eastward with movement and weakening of the Basin High at the surface, warming of the desert interior takes place. This heating induces a trough of low pressure to form at the surface over the deserts which is known as the thermal trough. As was discussed under "Onset of Stratus and Fog," the thermal trough causes a reorientation of the isobars along the coast such that onshore marine flow replaces the dry offshore Santa Ana winds. Thus, an increased warming over the interior generally brings an existing Santa Ana to an end. As is often the case with the atmosphere, it is difficult to isolate the formation and effects of one particular feature upon the weather pattern. Rather, it is observed that movement and weakening of the Basin High, formation of the thermal trough, strengthening of the onshore flow, and movement of the ridge

aloft to the east all occur together and cumulatively result in an end to Santa Anas.

Changes in Upper Air Pattern

Although the effects of the upper air pattern generally can not be isolated from patterns at the surface, it is useful to point out the more important changes that take place aloft in leading to an end of Santa Anas.

The decay and movement of the Great Basin High is associated with a corresponding change in the ridge and belt of northerlies aloft. The ridge characteristically moves inland and decreases somewhat in amplitude. This permits the belt of strong northerly winds aloft and associated region of strong subsidence, located previously over the coastal area, to move eastward also. Thus, there is much less dynamic support for a strong high at the surface over the Great Basin. In addition, as mentioned before, movement of the ridge over the interior usually leads to heating over the deserts and formation of a surface thermal trough.

Even though statistical studies performed so far have not revealed any significant quantitative correlations between Santa Ana duration on the one hand and depth of northeasterlies or strength of winds aloft on the other, it should be plain that northeasterlies aloft are much more favorable to Santa Ana continuance than westerlies. With northeasterlies, troughs and ridges are usually large in amplitude and are frequently "cut off," and if there are any movements, they are normally small. Surface features such as the Basin High are also very slow moving under these conditions and their intensity does not change appreciably with time. When northeasterlies aloft are very strong, it is very likely that a good deal of this energy gets supplied to the low level and surface winds. Thus, it appears that northeasterlies and large amplitude waves aloft are not conducive to Santa Ana abatement, but rather to its prolongation.

When upper waves are weakening and are of decreasing amplitude, and particularly if winds aloft over Point Mugu become westerly, there is a much greater likelihood of the Basin High moving off to the east and abatement of the Santa Ana in the very near future. When upper air sounding data are not available or applicable for the time in question, a simple method of determining the trend of winds aloft is to note the direction of movement of cirrus clouds, if there are any. When they appear to move from the west, it may be taken as further evidence that the Basin High is weakening and moving to the east and that the end of the Santa Ana is near (reference 25).

Return of Moist Sea Breeze

The appearance of a sea breeze during the afternoon of a Santa Ana day is not by itself sufficient indication of the end of the Santa Ana since as was pointed out earlier, it may only separate successive Santa Ana Bursts. However, if the sea breeze on a

given day interrupts the Santa Ana at a much earlier hour than it did, say, on the previous day, this should be taken as evidence of an increased tendency for onshore flow and abatement of the Santa Ana. Implied and usually accompanying the earlier sea breeze are all the changes and modifications in the surface and upper air patterns that were discussed previously. Moreover, if dewpoints are higher in today's sea breeze than they were in yesterday's, this is further evidence of abatement of the Santa Ana. Sea breezes between Santa Ana Bursts may be fairly strong at times but they are frequently more northwesterly than are the typical non-Santa Ana sea breezes, and are much drier, since they usually are only a slightly modified return flow of Santa Ana air cooled by the surface of the ocean. At Point Mugu, sea breezes at the end of a Santa Ana are usually much more moist, more polluted, and are frequently from the southeast, never from the northwest.

It is often argued that sea breezes and Santa Ana abatements are more likely when the sea surface temperatures are generally lower than normal. While the logic of such reasoning is plain, there is unfortunately no statistical evidence to support it, not to use as a base for a strong forecasting rule.

Re-establishment of Inversion

At the end of a Santa Ana and upon the return of marine onshore flow at the surface, a strong inversion is immediately established over the local area. With warm and dry air still present aloft at low levels, the inversion is normally quite low initially, gradually increasing in height with a deepening of the marine layer. This inversion is usually distinguishable from the shallower inversion formed between Santa Ana Bursts by virtue of the much sharper decrease of humidity between base and top.

Post-Santa Ana Weather

To summarize, the weather associated with the end of a Santa Ana can best be described as the gradual return to a marine environment. The northeast winds die down and are replaced by the re-established sea breeze regime. Following the last northeasterly gusts of wind, this sea breeze frequently starts out from the southeast and quite often is responsible for a flow of smoggy air into the local area from the Los Angeles Basin and offshore areas. Temperatures are normally lower and dewpoints are much higher than those observed during the Santa Ana. With time, the marine layer usually thickens to its normal depth and stratus and fog may return.

CLIMATOLOGICAL AND STATISTICAL STUDIES

Several statistical studies are being performed with computer-reduced surface and upper air data for Point Mugu and Vandenberg AFB to reveal correlations of wind patterns not recognizable to, or easily documented by, the forecaster on a day-to-day or

even year-to-year basis. Two samples are provided here to demonstrate the approaches being taken where useful data are already available regarding the Santa Ana problem.

One such output is provided as table 5-1 which shows hourly reports of Santa Anas by windspeed and hour of the day. (In the study a northeast wind is taken to be 10 knots or greater with relative humidity of less than 50%.) The study is based on Point Mugu surface data from 1949 to 1964 and in the example is for the month of October. Results from this one sample clearly indicate that Santa Ana winds in October occur more often at 0800 PST than any other hour of the day. This agrees pretty much with earlier descriptions of Santa Ana winds as being strongest and most frequent during the morning hours after sunrise.

The second sample is presented as figure 5-24 which relates the 1,000-meter winds at Vandenberg AFB to surface winds at Point Mugu for each hour of the day and each month of the year. The hodographs at the top of the figure show mean vector surface winds at Point Mugu for each season when there is no 1,000-meter wind at Vandenberg AFB. The various seasonal and synoptic wind regimes are recognizable from this figure. Diurnal hodographs of mean vector winds at Point Mugu for selected Vandenberg winds have already been shown as figure 5-12 and were discussed under "Weather Associated with Santa Anas."

COMPUTERIZED WIND FORECASTS

The PMR Weather Center each day prepares a computer-processed forecast of rainfall probabilities of various amounts for the 3 time periods, "Today," "Tonight," and "Tomorrow." These forecasts include an estimate of the maximum windspeed for each time period and they specify whether the wind will have an east or west component. Just before Santa Anas or during situations when synoptic conditions make them a distinct possibility, any forecast of east component winds for Point Mugu may be interpreted as a forecast of Santa Ana northeast winds. The only other east-component winds of any consequence are southeasterlies during strong eddies and ahead of active fronts. Thus, a knowledge of the synoptic situation can allow for easy elimination of two of the three east-wind component possibilities and lead to a correct interpretation of a Santa Ana wind forecast.

The computerized forecasts are based on surface pressures and pressure gradients, as well as heights, height changes, and vorticity values at 500 mb as obtained from 1200Z National Meteorological Center analyses each morning. Simple descriptions and outputs of the forecasts are presented under "Forecasting Active Fronts" as tables 8-2 and 8-3 in chapter 8.

Table 5-1. Local Santa Ana Windspeeds Versus Hour of Day for October 1949-1964

	Santa Ana Windspeeds (Knots) in Decreasing Order at Each Hour of the Day (PST)																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	26	26	26	24	25	23	20	25	27	25	26	28	23	32	32	18	22	16	24	23	22	24	24	24
	22	19	20	20	24	20	20	24	24	25	26	24	22	20	22	18	17		17	20	20	20	24	22
	17	16	19	20	26	20	19	23	24	24	25	24	21	20	17	16	16			10	16	19	18	20
	14	14	18	17	20	19	19	20	24	24	24	23	20	20	15	13	12				16	17	16	18
	12	14	17	15	18	17	18	20	24	23	24	23	20	19	14	13					10	14	15	15
	12	12	15	15	16	17	16	20	22	22	22	22	20	18	13						10		12	14
	12	11	14	13	16	16	16	18	20	22	20	20	20	16	12								10	10
	11	11	12	12	15	15	15	18	20	22	20	19	18	15										10
	10		11	12	15	15	14	17	18	20	18	17	17	13										10
	10		10	11	15	13	14	16	18	19	18	17	15											
			10	10	13	13	13	16	18	19	16	16	11											
				10	10	12	12	15	16	19	16	15												
					10	10	12	15	16	18	14	15												
						10	12	12	15	16	13	10												
							12	10	15	15	13	10												
							10		14	14	11													
							10		14	12	11													
									13	12	10													
									10	10	10													
									10															
									10															
									10															
									10															
Total Santa Anas Reported	10	8	11	12	13	14	17	15	23	19	19	15	11	9	7	5	4	3	2	3	6	5	7	9

From Helvey

FIGURE 5-24

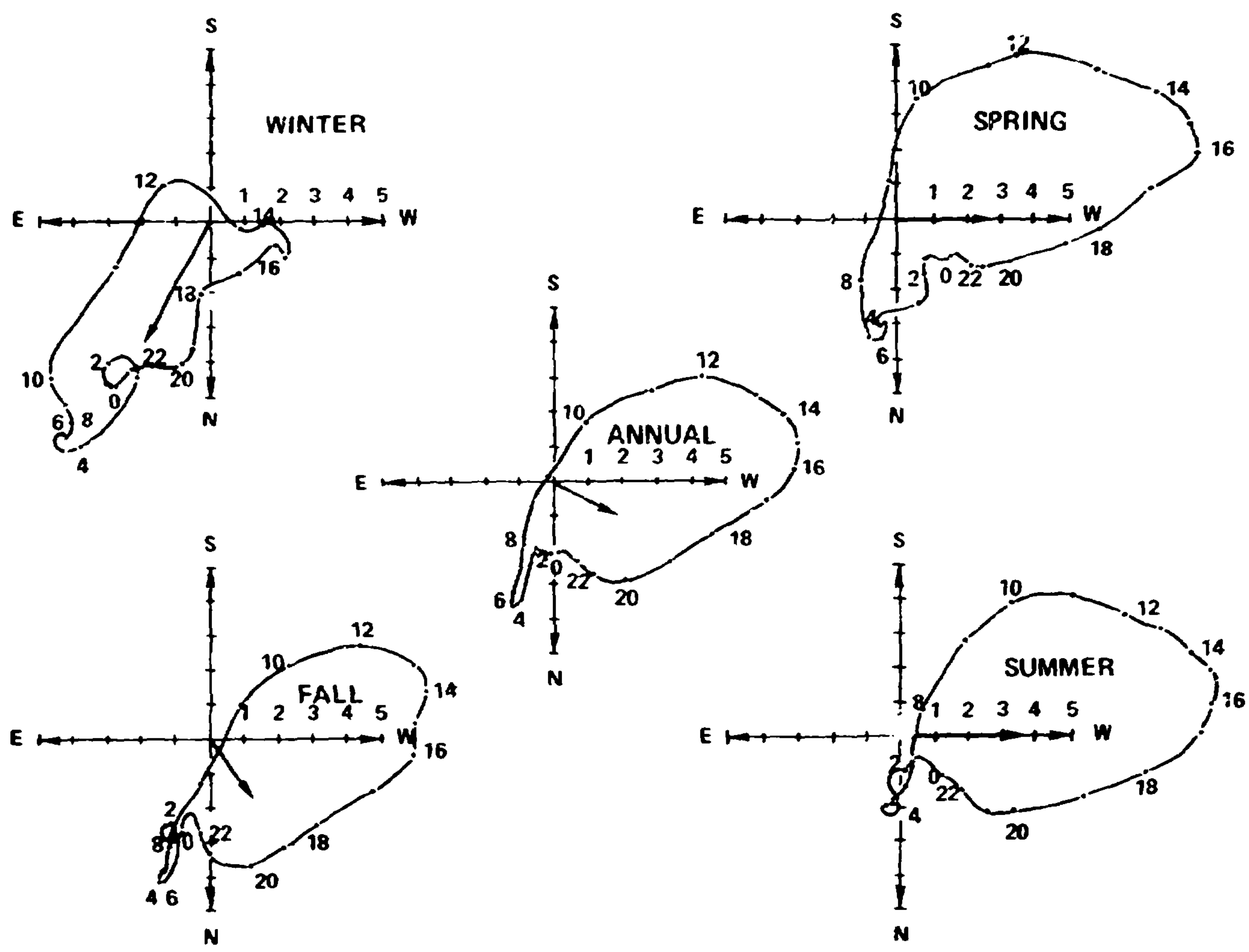

Figure 5-24. Diurnal and Annual Wind Behavior at Point Mugu as a Function of Windspeed and Direction at 1,000 Meters at Vandenberg AFB. (From reference 40.)

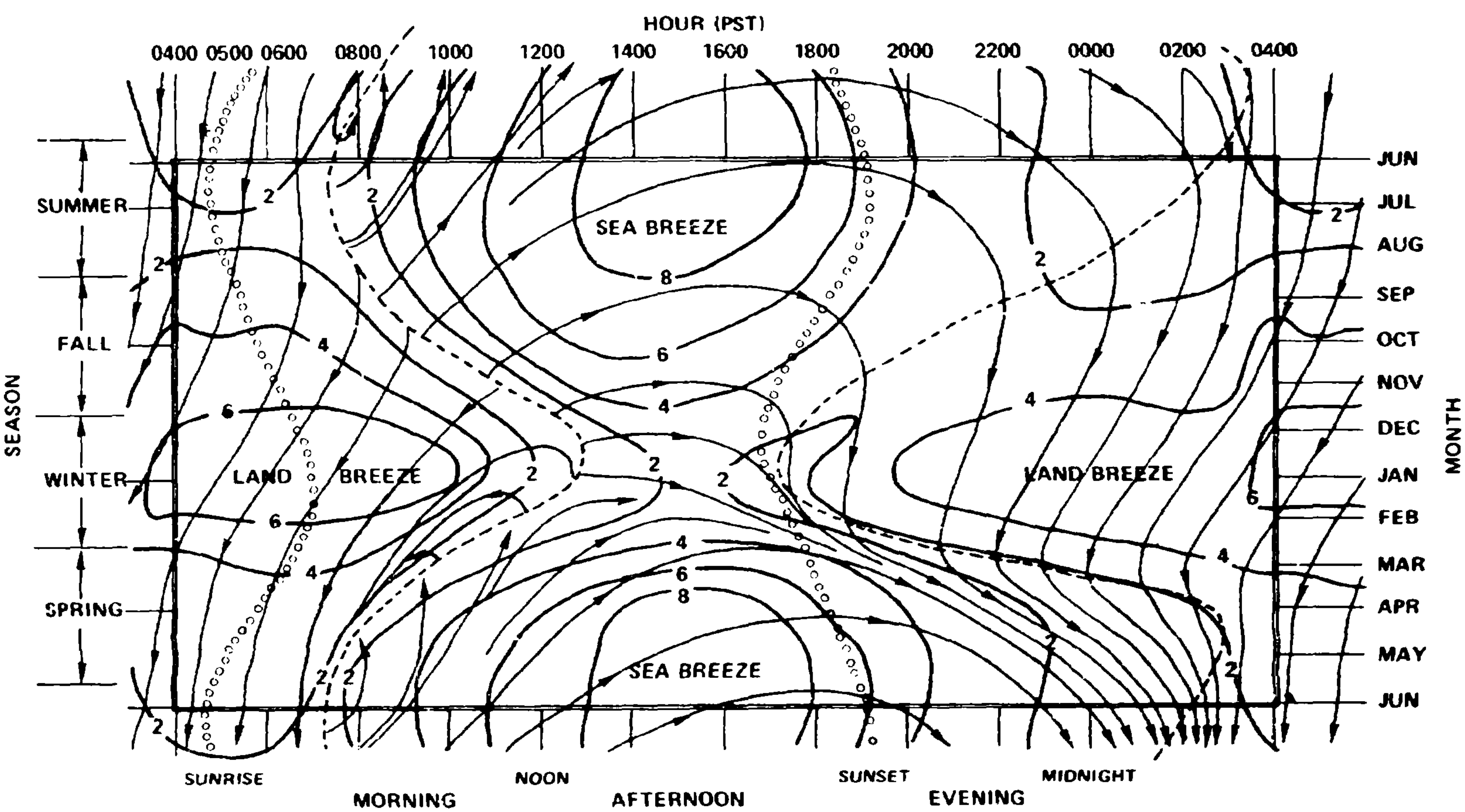

Figure 5-24. Concluded.

____
Date

SANTA ANA FORECAST GUIDE

(This forecast guide was revised by the Atmospheric Sciences Branch on 8 May 1970)

I. OCCURRENCE

There will be a Santa Ana at Point Mugu if the following conditions are met:

1. A surface high pressure area is building over or moving into the Great Basin such that the surface pressures at northern Nevada stations (Elko, and Reno) are 12 mb or more higher than at Point Mugu.

2. A cold trough aloft is located to the east of Point Mugu with a ridge building on to the coast such that there are strong northerly or easterly winds aloft.

II. TIME OF SANTA ANA ONSET

1. The most frequent time for Santa Ana onset is shortly after sunrise with the next most frequent time from sunset to midnight. Almost none begin from late morning (1100 PST) to sunset (1800 PST).

2. In the autumn and spring months, Santa Ana onset nearly always occurs just after sunrise. During the mid-season months of December and January, Santa Ana onset is most likely from sunset to midnight.

3. If there is a cold front passage marking the invasion of fresh polar air and the conditions in I holo true, Santa Ana winds will begin at Point Mugu after the following intervals for the given frontal orientations.

Frontal Orientation	Onset After Frontal Passage (Hours)
Northeast-Southwest	12 to 36
East-West	6 to 18
Southeast-Northwest or South-North	0

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SANTA ANA FORECAST GUIDE (Continued)

III. INTENSITY

1. Operationally, Santa Anas may be separated into small-craft (gusts to 33 knots), gale (gusts to 34 to 47 knots) and storm (gusts 48 knots or more). Two-thirds are of the small-craft type with almost all the rest in the gale category of Santa Ana.
2. The following pressure differentials between the Basin High and Point Mugu result (approximately) in the listed categories of Santa Ana intensity

Pressure Differential Between Point Mugu and Center of Great Basin High* (mb)	Santa Ana Intensity	Typical Maximum Winds (Knots) (Speed)	(Gust)
12 to 15	Normal, small-craft	20	32
16 to 24	Strong, gale	25	40
25 and above	Very strong, storm	30	48

*The Basin pressures are the higher.

3. Maximum Santa Ana winds are most frequent in mid or late morning hours, only a few hours before northeasterlies shift to afternoon sea breezes.
4. The maximum Santa Ana wind gust averages 1.6 times the maximum sustained speed.

IV. DURATION

1. The most frequent duration of a Santa Ana regime is about 24 to 30 hours; half last longer than 28 hours.
2. The most frequent duration of individual Bursts of northeasterlies is 4 to 6 hours, but considerable variation occurs from case to case.
3. Santa Anas last longer in November, December, and January than during the other Santa Ana months.
4. Santa Anas generally end between 1000 and 1500 PST; the most frequent time is from an hour before to an hour after noon.

SANTA ANA FORECAST GUIDE (Continued)

V. TEMPERATURE

1. Santa Anas result in maximum temperatures that are about 10° above normal in midwinter and about 15° to 20° above normal during the early fall and spring months.

2. The great majority of days with maximum temperatures of 90° or more occur with Santa Anas from the end of September to early November. At least one such occurrence can be expected each fall, often during the first or second Santa Ana of the season.

3. "Cold" Santa Anas occur when very cold arctic air moves from Canada to the Great Basin and results in near-normal maximum temperatures of less than 70°. "Hot" Santa Anas occur with well established, warm ridges aloft and result in temperatures 80° and above, particularly in fall.

4. Temperatures rise very sharply with onset of Santa Ana winds and decreases very sharply with sea breeze onset. Large diurnal variations in temperature are common during Santa Anas, and much-below normal temperatures may occur if Santa Ana winds temporarily stop during the early morning hours.

VI. HUMIDITY

1. Most Santa Anas result in humidities of less than 20% with typical dewpoint temperatures in the 20s and 30s.

2. Very sharp decreases in humidity occur with onset of Santa Ana winds and very sharp increases occur with onset of sea breezes.

3. Santa Anas following recent heavy rains or those occurring with cold, unstable upper lows in Southern California or Arizona are not as dry as typical ones.

VII. LAGUNA PEAK WINDS

1. Laguna Peak wind speeds are usually much stronger than surface winds during Santa Anas. The following approximate maximum wind speeds can be expected to occur at Laguna Peak for the appropriate intensity of Santa Ana at the surface.

Strength of Santa Ana Maximum Gust at Point Mugu	Maximum Sustained Speed at Laguna Peak (Knots)	Maximum Gusts at Laguna Peak (Knots)
Normal, small-craft (to 33 knots)	25	[illegible]
Strong, gale (34-47 knots)	35	55
Very strong, storm (48 knots or more)	45 or over	65 or over

2. Santa Ana winds begin earlier and end later atop Laguna Peak than they do at Point Mugu.

SANTA ANA FORECAST GUIDE (Concluded)

VIII. TYPICAL SANTA ANA DAY

1. Typical conditions are described below for the average Santa Ana at Point Mugu.

Night and Early Morning

Just before onset, skies are clear but still relatively cool and moist at the surface. Some shallow fog is possible but air gradually begins to dry slightly as temperature drops below normal. Santa Ana winds are already blowing on Laguna Peak. Just after sunrise, the winds reach the surface and gust from the northeast to about 25 knots. With onset of the Santa Ana, temperatures rise and humidities drop abruptly--almost instantaneously. Skies are quite clear and blue except for a little blowing dust at times.

Midmorning to Near Noon

Santa Ana winds increase and gust to about 32 knots with a little blowing dust, but skies are quite clear and visibilities excellent. Temperatures warm to about 10° or 15° above the normal maximum and humidities hover around 15%. Winds on Laguna Peak gust to about 45 knots.

Afternoon

At around noon, northeast Santa Ana winds suddenly decrease and give way to a west-northwest sea breeze of about 10 knots, accompanied by a decrease in temperature of about 10 or 15° and a rise in humidity of about 50%. Skies remain clear and visibilities excellent. Winds on Laguna Peak do not shift to westerly till midafternoon. After the initial drop in temperature, a slower increase sets in again, but temperatures do not reach their earlier peak.

Evening and Early Night

After sunset, winds become calm and skies remain quite clear with excellent visibility. Temperatures drop steadily and are usually well below normal. Santa Ana winds begin anew on Laguna Peak. Before midnight, northeasterlies gusting to 20 knots reach the surface accompanied by a sharp rise in temperature and a decrease in humidity.

Morning of Following Day

After sunrise, winds strengthen slightly and gust to 30 knots. By around 1000 PST, temperatures reach the daily maximum, nearly 15° above normal. Winds on Laguna Peak gust to about 35 knots. Visibilities are still excellent, but a layer of hazy pollution is visible offshore to the southeast. Before noon, Santa Ana winds end for the final time and are replaced by a southerly sea breeze with an accompanying sudden drop in temperature, a rise in humidity, and a drop in visibility.

NOTES, SPECIAL COMMENTS OR COMPUTATIONS.

THUMB RULES AND FORECASTING AIDS ON SANTA ANAS

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Santa Ana Onset				
Great Basin Highs with central pressures of 1035 mb or more usually cause Santa Anas.		√		5-6
Pressures over the Basin must be 12 mb or more higher than Point Mugu's for a Santa Ana to occur.		√		5-6, -69
The colder the Basin High, the greater the chance for Santa Anas.	√			5-6
Basin Highs do not have to be isolated or maritime in origin to cause a Santa Ana.	√			5-6
Maritime highs which move over the Basin may increase in pressure by 5 to 20 mb, frequently resulting in Santa Anas when they do.	√			5-6
Strong positive pressure tendencies over the Basin are good guides to future Santa Ana conditions.	√			5-6
A near-stationary high with central pressure 1040 mb or more in the Gulf of Alaska is not conducive to a Santa Ana later on.		√		*
Santa Anas are associated with a pronounced ridge aloft situated near the west coast and a deep trough located further to the east.	√			5-9
Santa Anas are more likely when there are strong northerlies or easterlies aloft.		√		5-17
Santa Anas at Point Mugu are preceded by a front or trough passage.	√			5-6
Dry fronts more likely precede Santa Anas than wet ones (NOTE. the great majority of all fronts passing Point Mugu are dry).	√			5-8, -9
One of four (25%) wet fronts are followed by a Santa Ana within 4 days.	√			5-9

*See chapter 9, page 9-11.

THUMB RULES AND FORECASTING AIDS ON SANTA ANAS (Continued)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Santa Ana winds follow passage of a NE SW oriented front by 12-36 hours, an E W front by 6-18 hours and a "back door" (SE-NW or S-N) front almost immediately.		✓		5-7,-8
Santa Anas are most frequent in late autumn or winter but almost never occur in summer.	✓			5-19
The preferred time of Santa Ana onset at Point Mugu is just after sunrise but many (particularly in winter) start at night.	✓			5-19,-21
Thermal mixing and destruction of the inversion trigger the morning onset of Santa Anas.		✓		5-23
Santa Anas begin on Laguna Peak before they do at Point Mugu.		✓		5-49
Santa Anas are more likely to occur at Point Mugu if Vandenberg and South Mountain (Santa Paula) report northeast winds.			✓	5-51
A Santa Ana may occur when on a very hazy day, the sky looking vertically seems especially blue and clear.			✓	5-57
A warm Santa Ana is likely if an open warm sector accompanies a low centered off the California coast.		✓		5-6
Santa Anas are less likely if desert stations are very hot.		✓		5-61,-57
Associated Weather and Features				
Skies and visibilities and general features				
Santa Anas most often consist of two bursts of northeasterlies separated by an afternoon sea breeze. The first usually starts after sunrise, the second most often at night.	✓			5-23,-61

THUMB RULES AND FORECASTING AIDS ON SANTA ANAS (Continued)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Santa Anas bring clear, dry, and warmer than normal weather.	\			5-35, -37, -45
Skies during Santa Anas are usually cloudless and very blue.	\			5-35, -37
Visibilities during Santa Anas are usually excellent.	\			5-35
Visibilities during very strong Santa Anas may be restricted by blowing dust.	\			5-35
Winds				
Santa Ana winds at Point Mugu are northeasterly and gusty.	\			5-24, -29
The most frequent maximum wind is 15-19 knots with gusts to 25-29.	\			5-25
Two-thirds of Santa Anas are small craft (gusts to 33 knots) and almost all of the remainder are gale Santa Anas (gusts 34-47 knots)	\			5-25
Storm Santa Anas (gusts 48 knots or more) are rare.	\			5-25
Maximum Santa Ana winds most often occur in mid-morning, shortly before sea breeze onset. They never occur in late afternoon.	\			5-29
Laguna Peak winds are stronger, begin earlier, and last longer.	\			5-31, -49
Worst operational weather occurs on first day and first burst of Santa Ana.	\			5-29
The gust factor (ratio of maximum gust to maximum sustained speed) averages 1.6.		\		5-30
Stronger Santa Ana winds persist till later in the day than weak ones.		\		5-61

THUMB RULES AND FORECASTING AIDS ON SANTA ANAS (Continued)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Seldom do Santa Ana winds blow continuously all day at Point Mugu; normally they are interrupted by an afternoon sea breeze which blows from the WNW.	√			5-23,-63
Spatial variations of local Santa Anas are great, winds being less prevalent with proximity to the beach and more prevalent with proximity to Laguna Peak.		√		5-48,-49
Santa Anas may extend tens of miles to sea at the surface.			√	5-52,-53
Santa Ana winds are less frequent and weaker at San Nicolas Island then at Point Mugu.	√			5-51
Santa Anas are more likely if there are strong northerlies or easterlies aloft.		√		5-17
Santa Ana winds are likely most of the day at Point Mugu if Vandenberg AFB winds at 3,000 feet are moderate from the east.	√			5-35
Strong vertical wind shears and turbulence are common just above the surface during Santa Anas, particularly when the Santa Ana is interrupted at the surface by a temporary sea breeze.	√			5-30,-31
Temperature				
Santa Anas usually result in warmer than normal temperatures.	√			5-37,-39
Santa Anas are warmest in the spring and fall, both in absolute and relative warmth.	√			5-39, -42,-43
Cold Santa Anas (max. temp. less than 70°) occur mainly in winter, frequently blow at night, and are often associated with lows aloft.			√	5-39, -42,-53
Hot Santa Anas (max. temp. 80° or more) are associated with warm ridges aloft and pronounced subsidence from high levels.	√			5-39

THUMB RULES AND FORECASTING AIDS ON SANTA ANAS (Continued)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Cold Santa Anas average only slightly above normal in max. temperature, hot Santa Anas average 15 or 20 degrees above normal.	√			5-39, -42
The great majority of 90° days at Point Mugu occur with Santa Anas from late September to early November.	√			5-39
Heavy November rains follow hot Santa Anas.			√	5-39
There is no apparent correlation between warmth and strength of Santa Anas.		√		5-45
When Santa Ana winds temporarily subside, nights may be very cold.	√			5-44, -45
Temperatures usually rise dramatically with Santa Ana onset and decrease just as dramatically with onset of a sea breeze.	√			5-42, -43
Humidity				
Minimum relative humidities in most Santa Anas are less than 20%.	√			5-45, -46
Humidity decreases dramatically with Santa Ana onset and increases just as dramatically with onset of a sea breeze.	√			5-46
Pressure				
Surface pressures at Point Mugu during Santa Anas average only slightly higher than stratus season or annual mean values but vary considerably from case to case.			√	5-47
Rainfall				
Sprinkles of rain may fall from a thick mid-overcast during a true Santa Ana (but it is rare).	√			5-54

THUMB RULES AND FORECASTING AIDS ON SANTA ANAS (Concluded)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Most instances of rainfall (and snowfall) during northeasterly winds at Point Mugu are not associated with true Santa Anas.		✓		5-54
Pseudo or "cyclonic" Santa Anas often become or develop from real Santa Anas.	✓			5-54, -10
Bursts				
Successive Santa Ana Bursts get warmer, shorter, and less windy.	✓			5-61
The most frequent duration of a Santa Ana Burst is 4-6 hours, but this can vary considerably.	✓			5-61
Duration and Abatement of Santa Anas				
Santa Anas abate when the Great Basin High and ridge aloft decay or move eastward and/or when a thermal trough of low pressure gets established between Point Mugu and the deserts.	✓			5-61
The most frequent total elapsed time for a Santa Ana Regime is 24-30 hours (about a day and a half) and such a Regime typically contains 12-18 hours of Santa Ana winds.	✓			5-60, -61
Santa Ana Bursts are most frequently 4-6 hours in duration but vary greatly from case to case.	✓			5-61
Santa Anas last longer in November, December and January.	✓			5-60
Ending times of Santa Anas are almost exclusively limited to daylight and most frequently occur just after noon.	✓			5-19, -23 -60
An earlier sea breeze today than yesterday indicates Santa Ana end is near.		✓		5-62, -63
Cirrus clouds moving from the W indicate Santa Ana end is near.		✓		5-62
Sea breezes between Bursts are from the WNW, sea breezes at the end of a Santa Ana are frequently from the southeast and advect smog into the local area from offshore.		✓		5-63

CHAPTER 6.

TYPICAL FAIR WEATHER DURING COOLER MONTHS

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CHAPTER 6

DISPLACEMENT AND MODIFICATION OF SEMIPERMANENT SUBTROPICAL HIGH

During the fall months, there is an appreciable weakening of the semipermanent, subtropical high which is responsible for Point Mugu's persistent summertime stratus. Portions of the high periodically invade the Pacific coast and strengthen over the Great Basin region to produce Santa Anas. More often, this mound of high pressure, known as the Pacific High, is displaced, modified, and sometimes eliminated by a series of cold wave-like distrubances that develop and move through the northeast Pacific

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area. As winter approaches and the atmospere in the Northern Hemisphere is cooled, these disturbances become much more active and the westerlies aloft move progressively equatorward. The upper-air troughs are nearly always accompanied by surface lows which normally remain to the north of Point Mugu, even in midwinter. While the frontal systems trailing from these lows usually separate maritime polar air masses that differ only slightly in temperature and humidity characteristics, the considerable moisture available from the ocean results in extensive frontal clouds which provide Point Mugu with much of its annual rainfall. Statistically, about 95% of Point Mugu's rainfall occurs from November through April (reference 45) as a result of the migratory lows and their associated frontal systems. Figures 6-1(a) through (l) show the principal tracks of the centers of the lows for North America and the northeast Pacific Ocean for each month of the year (reference 46).

Between fronts and troughs are periods of more anticyclonic weather which range from dry Santa Ana conditions to the low stratus characteristics of summer months. More typically however, these in-between periods of "fair" weather are characterized by clear or scattered sky conditions, cool temperatures, diurnal land and sea breezes, and fine operational weather.

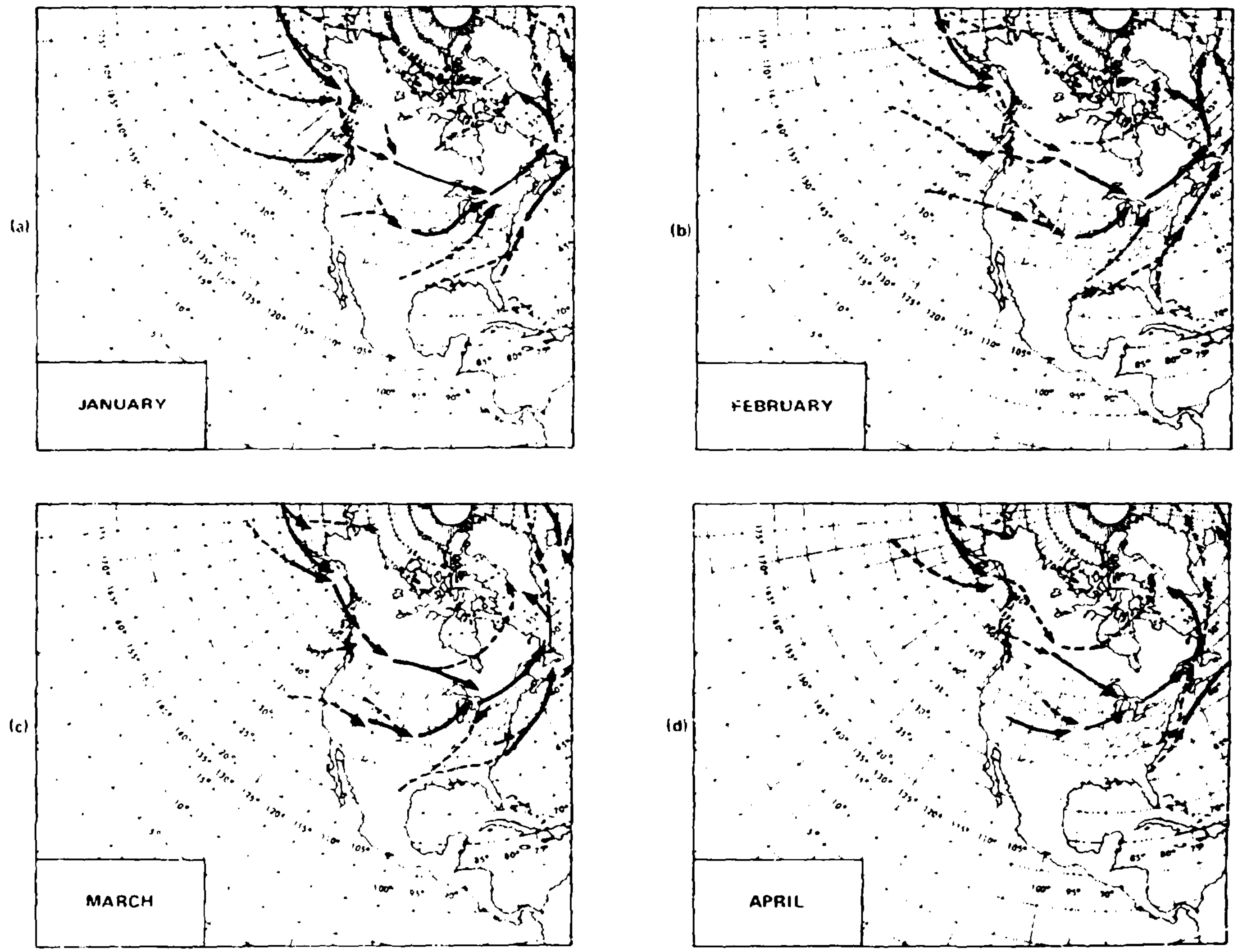


Figure 6-1 (a-d). Principal Tracks of Lows Over Northeast Pacific and North America. (From reference 46)

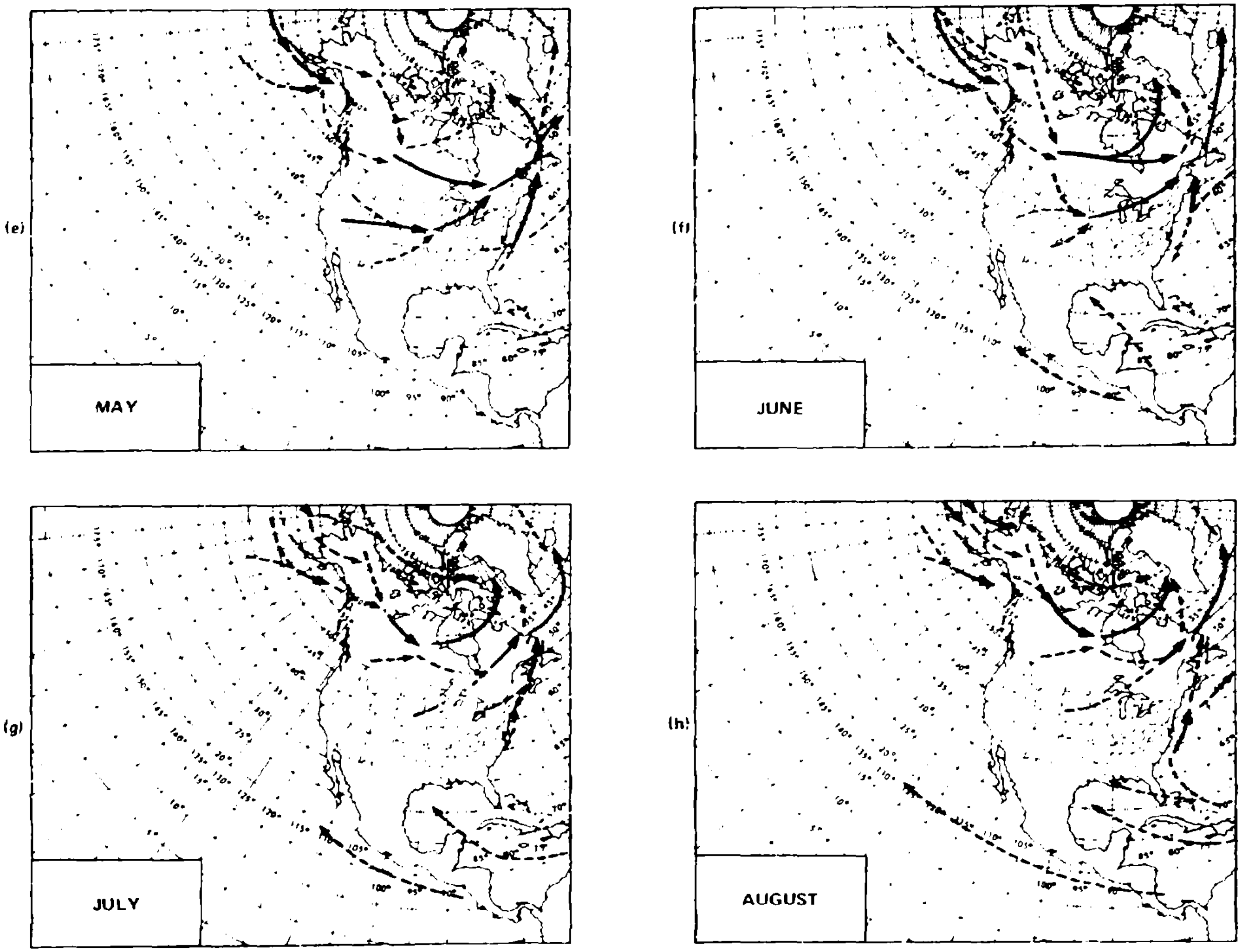
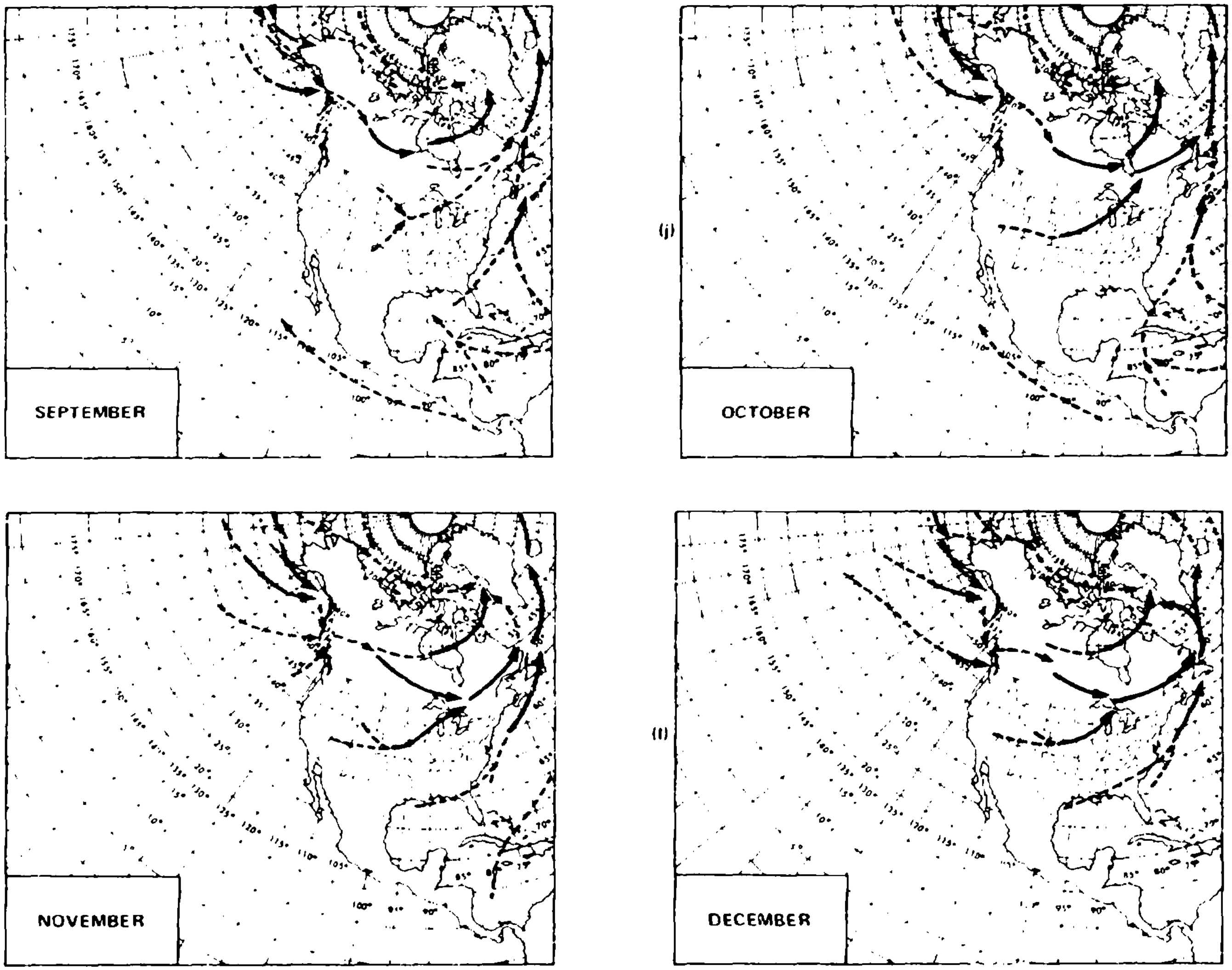


Figure 6-1 (e-h). Principal Tracks of Lows Over Northeast Pacific and North America. (From reference 46)

(i) (j)



(k) (l)

Figure 6-1 (i-l). Principal Tracks of Lows Over Northeast Pacific and North America. (From reference 46)

WINDS, LAND - SEA-BREEZE

Point Mugu surface winds during typical cool-season fair weather are controlled by the land- sea-breeze regime and are not marked by winds of great intensity. In response to daytime heating, a sea breeze begins in late morning and reaches a maximum intensity of approximately 10 or 15 knots during the afternoon hours. This sea breeze is sometimes southerly during its early stages, but usually veers to westerly by midafternoon. By evening, the sea breeze diminishes and is replaced at night by a weak offshore drift or land breeze. This drift normally does not exceed 5 knots and generally stops blowing within 2 hours following sunrise.

VISIBILITY

Fair-weather visibilities, while not as excellent as those which typically accompany Santa Anas, are usually unrestricted because of a general absence of stratus and associated fog. When visibilities are restricted, it is usually due to a shallow, light fog condition during early morning and to smog and pollutants in the afternoon. Occasionally, however, very dense fog will form within a shallow marine layer that is very moist and becomes cooled easily due to radiative heat loss. Some of the densest fogs observed at Point Mugu are of this type and occur most often from November to January when days are shortest. Fogs of this type result in "zero-zero" conditions and seem to occur most frequently just before and just after Santa Anas.

SKY CONDITIONS

Clear skies or clouds that cover no more than about one-third of the sky are typical during cool-season fair weather. When clouds are observed, they are generally cirrus, fair-weather cumulus, or just scattered stratus or stratocumulus elements, particularly in early morning. Cirrus is generally associated with the polar or subtropical jet streams or with the overrunning moist air that serves as a forerunner of far-away frontal systems. Fair-weather cumulus usually occurs during the days immediately following a frontal passage when the air is still slightly unstable. Over the mountains and nearby Laguna Peak, orographic lifting may result in somewhat larger cumulus buildups. Scattered stratus or stratocumulus occur primarily during the morning hours within a marine layer capped by a weak to moderate inversion except during the dense fog situations noted previously. Even then, with horizontal visibilities of about zero, stars and moon at night may be clearly visible overhead. Occasionally during fair weather, when a frontal system is approaching the station or is lying nearly stationary north of the local area, there may be considerable moisture aloft, and scattered midclouds may persist for a few days.

INVERSION

The inversion is not as persistent nor as strong a feature as it is during the warmer stable months of summer. Nevertheless, an elevated inversion is discernible on most cool-season soundings at fairly low levels, particularly during fair weather. It is strongest just before and just after Santa Ana conditions, when subsidence is pronounced. Even when there is no inversion or when it is very weak, a moist marine layer is usually present. The approach of a front or trough often results in a marked deepening of the marine layer and the inversion may be observed to rise by more than 5,000 feet in a day or so. A marked weakening of the inversion accompanies such lifting.

In addition to elevated inversions, a shallow, surface-based inversion layer is often present during cool-season mornings, particularly after cold, clear nights. It is due to the strong radiational cooling from the surface and is aided by cold-air drainage from nearby terrain. At times it may even merge with an elevated layer but most commonly, it is markedly weakened or destroyed by late morning by surface heating from the sun.

UPPER-AIR PATTERN

During typical cool-season fair weather, a broad westerly current with small amplitude troughs and ridges is usually observed aloft. When the amplitude of waves is large, fair weather will still occur when Point Mugu is geographically located under or upstream from the ridge but still well ahead of the next approaching trough.

TEMPERATURE

Temperatures during fair weather show a pronounced diurnal variation but the degree of warmth or cold is dictated largely by the time of the year. Due to the presence of a marine layer most of the time, very warm temperatures do not occur, even under pronounced ridges, unless Santa Ana winds are actually blowing at the surface, and thereby displacing the marine layer. On the other hand, when fresh polar air moves over southern California, minimum temperatures on clear, calm nights may lower to the 30s or less, setting records for Point Mugu. On 30 and 31 December 1969 and on 4 January 1970, fair weather days occurred within a general period

of Santa Anas but no Santa Ana winds were actually observed; minimum temperatures recorded were 30°, 29°, and 29°F, respectively, all records for the date. The two 29° readings tied the all-time record.

PRESSURE

Atmospheric pressure during fair weather is controlled largely by the time of day; however, pressure exhibits a semidiurnal cycle with peaks occurring near 1000 and 2300 PST and dips occurring near 0400 and 1600 PST. The amplitude of the oscillation above the mean is only about 1 mb (reference 2) so that it is frequently masked when fair weather is replaced by active frontal weather. During fair weather, sharp rises or falls in pressure are unlikely and average near the annual mean pressure at Point Mugu of 1,015 mb. Small month-to-month variations in mean pressure occur as a result of seasonal differences in the Pacific High.

SAN NICOLAS ISLAND AND THE SEA TEST RANGE

Fair weather at San Nicolas Island and the Sea Test Range is similar to that at Point Mugu but with less extreme temperatures, lower visibility, and somewhat higher incidence of low clouds and high humidity. One notable difference is that winds over the offshore waters and around San Nicolas Island are consistently from the northwest during fair weather.

CHAPTER 7. DRY FRONTS AND WEAK UPPER TROUGHS

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CHAPTER 7

DESCRIPTIONS

The great majority of fronts that pass Point Mugu are dry cold or occluded fronts. They are termed dry because at the time of their passage, there is no precipitation and little cloudiness associated with them. In summer, even higher clouds are absent and they serve only to temporarily raise the height of the inversion and associated stratus, sometimes dissipating the stratus in the process. During the cooler months, dry fronts usually result in a change of air mass, but to the observer these changes may be slow and subtle.

A correspondingly weak trough aloft is associated with every weak, dry front. The amplitude and position of this trough with respect to the front often has a lot to do with why the front is dry. For instance, if the trough is neither cold nor sharp, both

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a low-level flow of moisture and a sufficient instability to convert the available moisture to clouds and rain may be lacking. When the trough aloft moves out ahead of the surface front, a shearing off of upper clouds often takes place and the pre-existing heavy frontal band of clouds and rain dissipates. Thus, by the time the surface front passes the station, it may be poorly defined. But dry fronts and weak troughs are important to Point Mugu in the forecasting of such phenomena as the height of summertime stratus, the occurrence and time of onset of Santa Anas, and the occurrence of strong westerly winds.

Figure 7-1 shows an ESSA 8 satellite picture of a dry front which passed through the Point Mugu area on the morning of 6 March 1969. The front shows up as an arc of low clouds stretching hundreds of miles out to sea. That the frontal band is composed of only low clouds is evidenced by the fact that the cloud band comes to an abrupt end at the Baja California coastline. Surface observations for Point Mugu on 5 and 6 March 1969 confirmed the passage of a dry front; stratus and stratocumulus moved in, creating a low ceiling almost continuously from 2232 PST on 5 March to about 0457 PST on 6 March. During the daylight hours and later that afternoon, only scattered stratocumulus and cumulus were observed, and good visibilities, relatively low humidities, and strong west winds gusting to a peak 34 knots indicated the presence of a fresh polar air mass.

Figure 7-1 Dry Front Marked by Band of Stratus and Stratocumulus, ESSA 8 APT, 6 March 1969, 1819-1839 Z.

Figures 7-2(a) and (b) and 7-3(a) and (b) show the surface and the 500-mb maps for 1200Z on 6 March and 0000Z on 7 March, about 6 hours before and after the time of the satellite picture. At the surface, the southeastward progression of the front through southern California is readily apparent. The low-pressure center associated with the front is inland over the Utah-Wyoming area so that relatively dry northwest gradient flow both precedes and follows the front as it passes through the local area. At 500 mb, a pronounced trough and cold low moving across the western states is evident. During the passage of the trough, the jet stream remains just to the north of the station. With the low aloft and the coldest air staying well to the east, large convective clouds at the coast are probably inhibited by subsidence in the increasing northwesterly flow. Since there was no southerly wind component over southern California, there was also probably very little moisture advected into the local atmosphere with which to form appreciable mid- and high-frontal clouds.

The preceding example may be considered typical of a fast-moving dry front. Other slightly different types will be discussed under "Forecasting Dry Fronts."

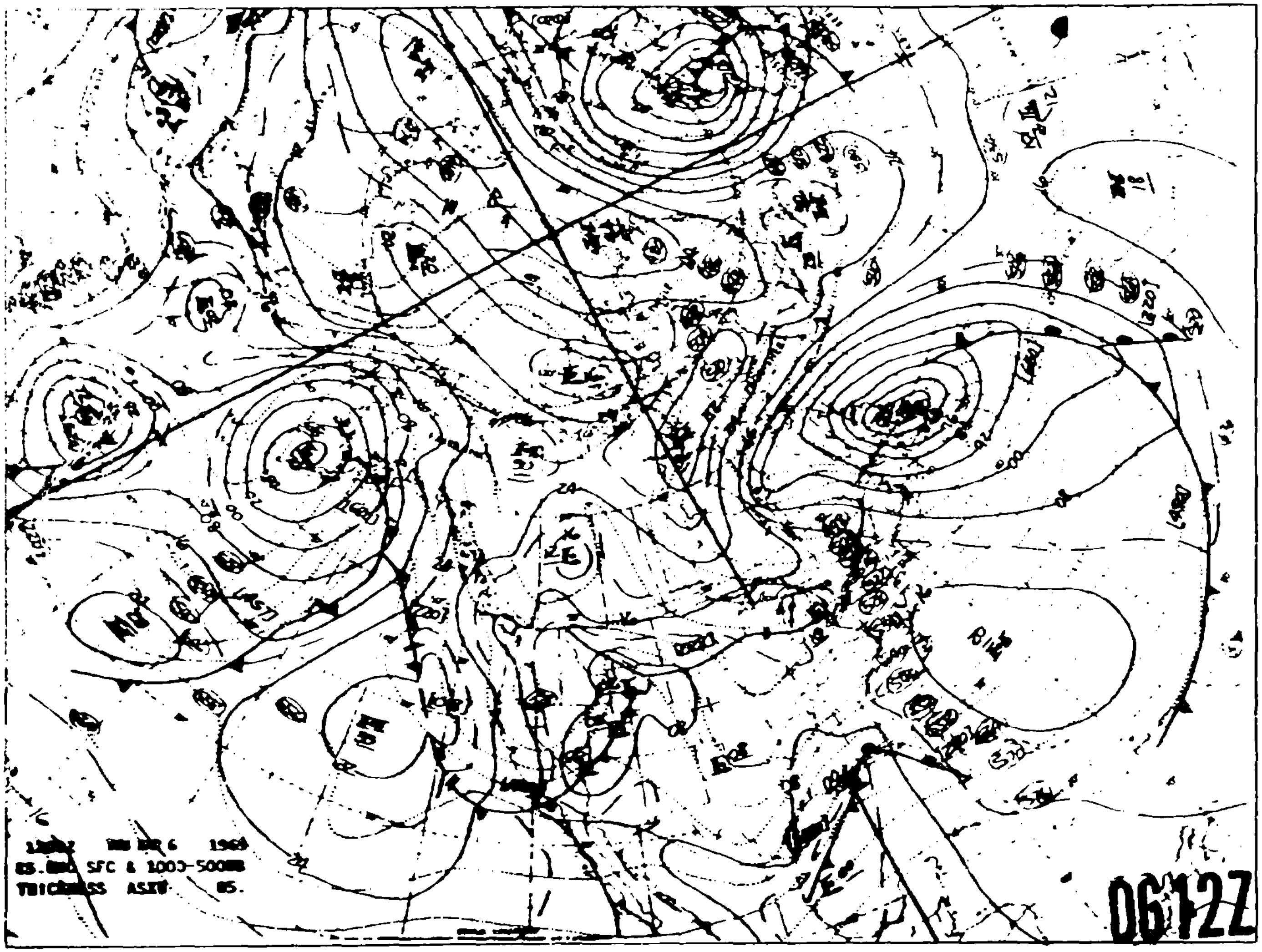

Figure 7-2(a). Surface Analysis of 1200 Z, 6 March 1969. National Meteorological Center Map.

FIGURE 7-2(b)

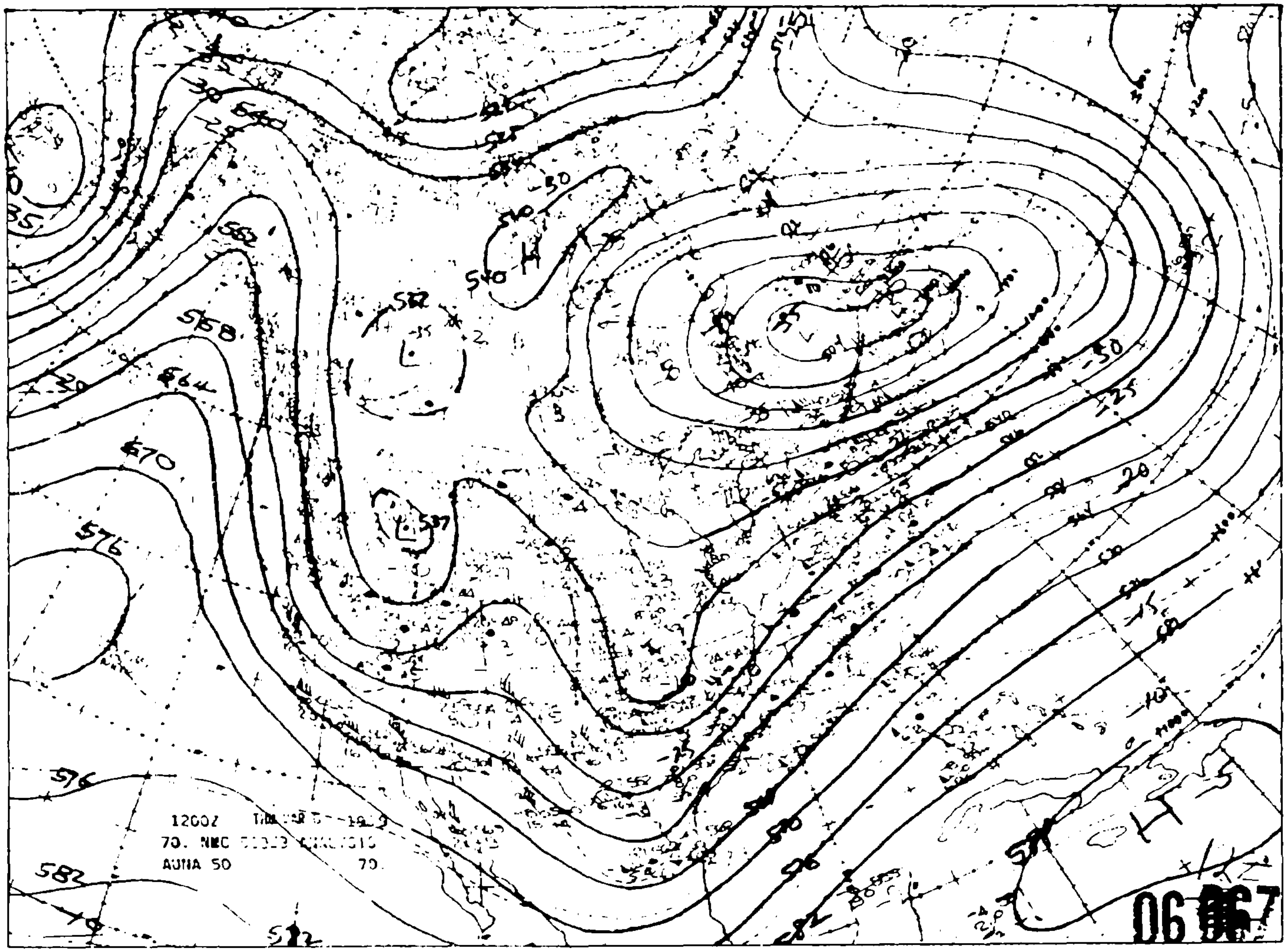

Figure 7-2(b). 500-Millibar Analysis of 1200 Z, 6 March 1969. National Meteorological Center Map.

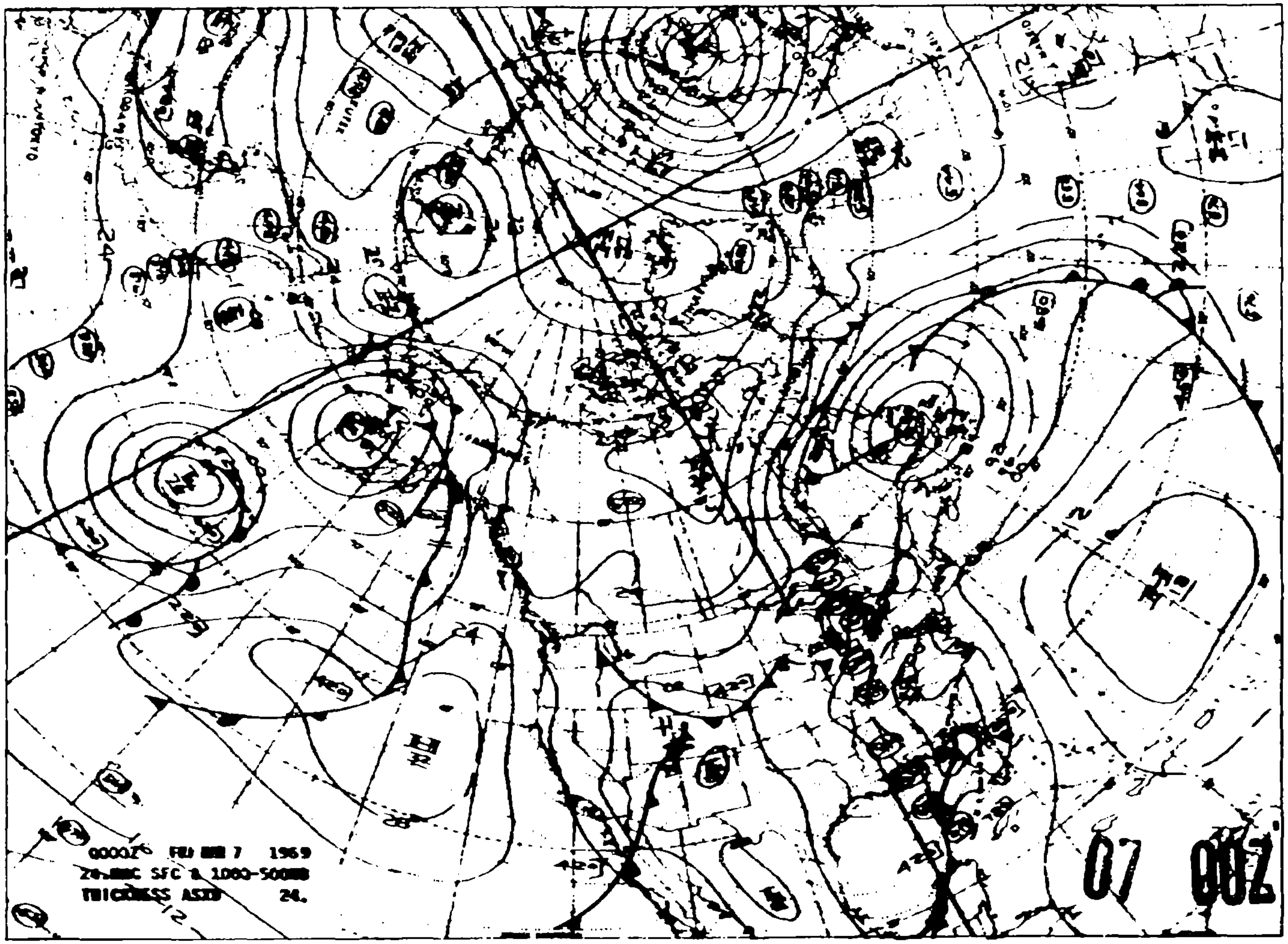

Figure 7-3(a). Surface Analysis of 0000 Z, 7 March 1969. National Meteorological Center Map.

FIGURE 7-3(b)

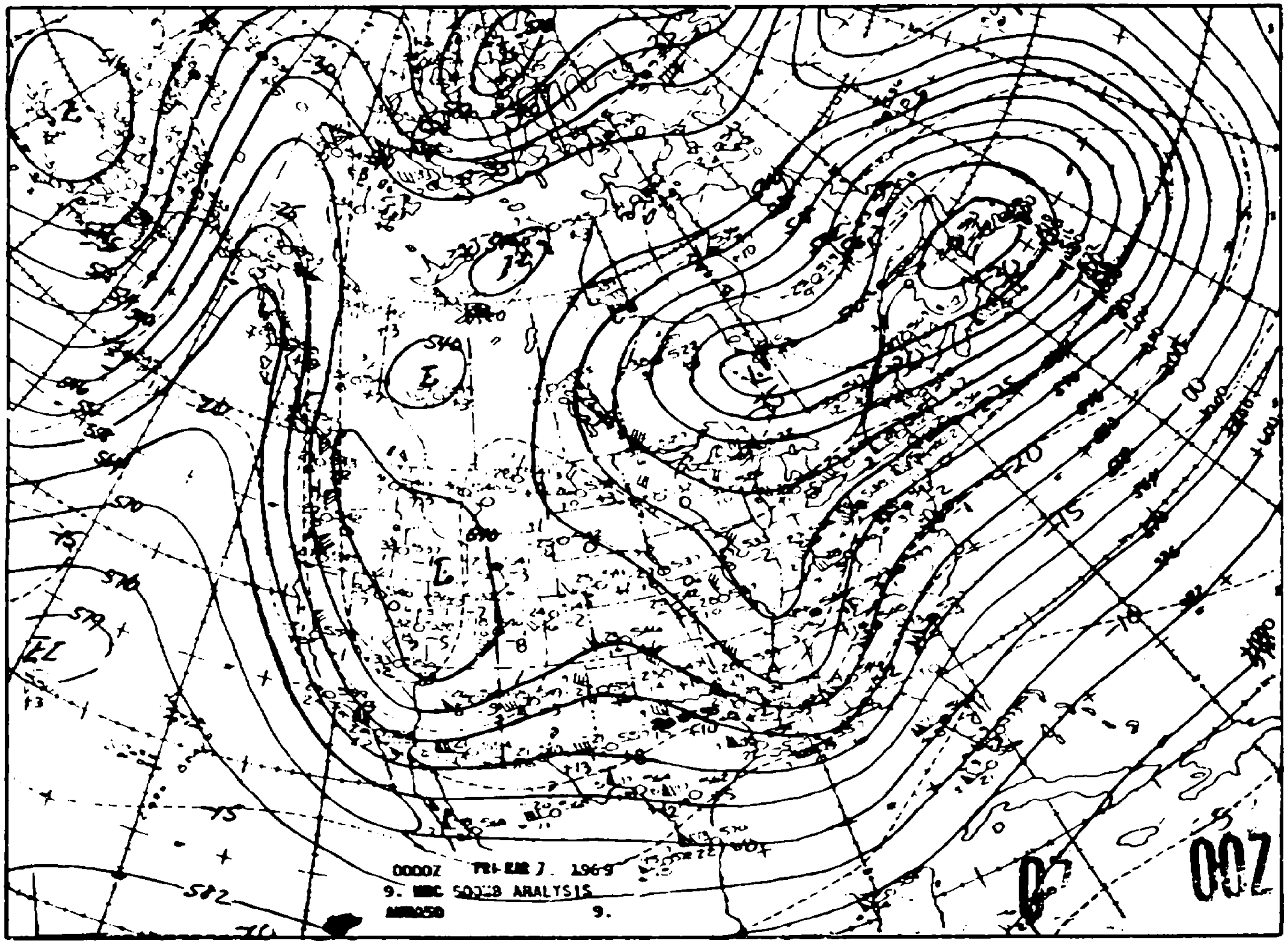

Figure 7-3(b). 500-Millibar Analysis of 0000 Z, 7 March 1969. National Meteorological Center Map.

TYPICAL WEATHER ASSOCIATED WITH DRY FRONTS

Sky Conditions

In summer, dry fronts are preceded by a lifting of the base of stratus and sometimes followed by temporary clearing. During the cooler months, dry fronts are frequently marked by variable high cirrus and scattered to broken midclouds. The midclouds are usually in the process of dissipation or evaporation and a truly dry front will rarely produce a complete midovercast at Point Mugu. Following frontal passage, skies will generally clear and there will be a temporary period of local fair weather or Santa Ana conditions.

Visibility

Visibility is apt to be much better with a fast-moving dry front than with a slow-moving dry front, because fast-moving fronts are normally associated with a well-mixed, fresh atmosphere of polar origins; slow-moving fronts are associated with stable, stagnant conditions during which fog and smog often prevail over widespread areas of coastal southern California.

Winds

With the fast-moving dry front, which typically approaches Point Mugu from the northeast Pacific, winds will be weak to moderate ahead of the front and rather brisk or strong westerly immediately behind the front. This postfrontal increase is particularly observable when frontal passage occurs early in the day so that postfrontal winds are aided by the usual daytime sea breeze component. This effect is most pronounced in March, April, and May, when the Pacific High is quite strong and the desert interior is just beginning to warm up.

With the slow-moving front, winds are generally weak both ahead of and behind the front. An important exception concerns the slow-moving polar front that occasionally passes Point Mugu from the east. In this case the cold continental high located over the Plateau will produce strong Santa Ana winds immediately following frontal passage. Whenever dry fronts move through the area during the cooler months, Santa Anas remain a firm possibility in the hours and first days following frontal passage, and the forecaster should evaluate other synoptic features and reports to see if they are favorable to Santa Ana development.

Effects on Range Operations

Since little in the way of precipitation and persistent low ceilings is associated with dry fronts, the effects on range operations would appear to be restricted almost exclusively to winds. It seems that the highest winds and greatest turbulence follow fast-moving dry fronts from the west which produce

strong westerly winds and slow-moving dry fronts from the east which produce strong northeast winds.

San Nicolas Island and Sea Test Range Area

With respect to cloud and visibility conditions, San Nicolas Island and the Sea Test Range area experience dry frontal weather similar to Point Mugu's. However, these seaward areas are more susceptible to strong northwest winds following dry frontal passage from the west (frequently resulting in wind warnings) and are slightly less susceptible to strong northeast winds and frontal passages from the east.

FORECASTING DRY FRONTS

Causes

When a trough moves through the polar westerlies over the North-Pacific, there is an associated impulse or surge of fresh polar air at low levels. Whether the boundary between the retreating and advancing polar air mass is perceivable at the surface in terms of clouds, rain or other visible weather is largely dependent upon the intensity of the system, the availability of moisture, and the time of year. If a cold and stable marine layer persists at the surface, only the higher aspects of the system may be observed, as the disturbance may ride up and over the surface layer.

Troughs and fronts are frequently undergoing either intensification or dissipation as they move toward the west coast and lower latitudes to Point Mugu and soutnern California. Dry fronts are generated when the disturbance greatly dissipates, usually because of a combination of cloud-destroying subsidence in northerly flow and lack of moisture. Most of the dry fronts experienced at Point Mugu arrive from the northwest, dried out from subsidence. A few others in fall and winter arrive from the east as leading edges of cold, dry continental air, and result in strong Santa Ana winds. Other dry fronts arrive in the summer stratus season as weak surges of fresh marine air which frequently ride up and over the pre-existing and firmly established marine layer.

Frequency

It is very difficult to assign any firm numbers to the frequency of dry frontal passages at Point Mugu because they are often difficult to observe due to the lack of marked change in conventional weather parameters such as temperature, pressure, and cloudiness at individual stations. It is possible, however, to infer a crude estimate by referring to figure 4-16 which shows the height variation of the inversion at San Nicolas Island for afternoons from 1 April 1964 to 1 April 1965. When the assumption is made that the large undulations in height are due to trough passages which are, in turn, associated with the passage

of fronts at low levels, an estimate of the total number of fronts in that 1-year period (assumed to be typical) is about 25 for the period 1 April to 31 October 1964, and probably another 25 or so for the period 1 November 1964 to 1 April 1965. The number of fronts for this latter "rainy" period must be considered quite conservative since absence of strong, persistent inversions permits only the roughest estimates, and numerous active or wet fronts frequently traverse the region during those same periods without inversions; in fact, they contribute immeasurably to the destruction of the inversion. From independent studies, (reference 38) it appears that there are about 5 "active" frontal passages a year and there are probably another 10 per year which produce rain and can be called wet but which are not well defined enough to be classified as active fronts.

When the number of these wet fronts are substracted, it seems reasonable that at least 35 or 40 dry fronts pass through the Point Mugu area in an average year. During the warmer months they are detectable by only the subtlest of changes in weather, and frequently do not appear analyzed on National Meteorological Center surface maps as they move through southern California. During the cooler months, dry fronts are slightly more detectable due to continuity from satellite pictures more than anything else. In either case, an after-the-fact modification or change in the weather is often the only clue to dry frontal passage rather than any frontal weather itself.

Preferred Paths (Fronts)

The paths of dry fronts through coastal southern California are, with very few exceptions, the same as for all fronts, wet and dry. Proximity to parent low often is the deciding factor which determines the dryness. In summer, when all fronts passing the Point Mugu area are dry, fronts move primarily from the northwest, **down the west coast** of the mainland, and southeastward through southern California. Summertime dry fronts, already weakly defined at the outset of their downcoast trek, weaken further as they move southward and are virtually dissipated as a synoptic feature by the time they reach northern or central Baja California. The inland portions of the front are destroyed even earlier as a low-level feature in crossing the hot desert regions. The preferred paths of movement and successive positions of these fronts are schematically illustrated in figure 7-4(a).

Figure 7-4(b) shows the corresponding schematic paths for wintertime dry fronts. The major preferred path indicated is again down the coast from the northwest to the southeast, but since the westerlies and cyclonic activity at this time of the year are located much further south, dry fronts are somewhat distinguishable down to the bottom of Baja California and sometimes beyond. Many of these fronts are

FIGURE 7-4(a)

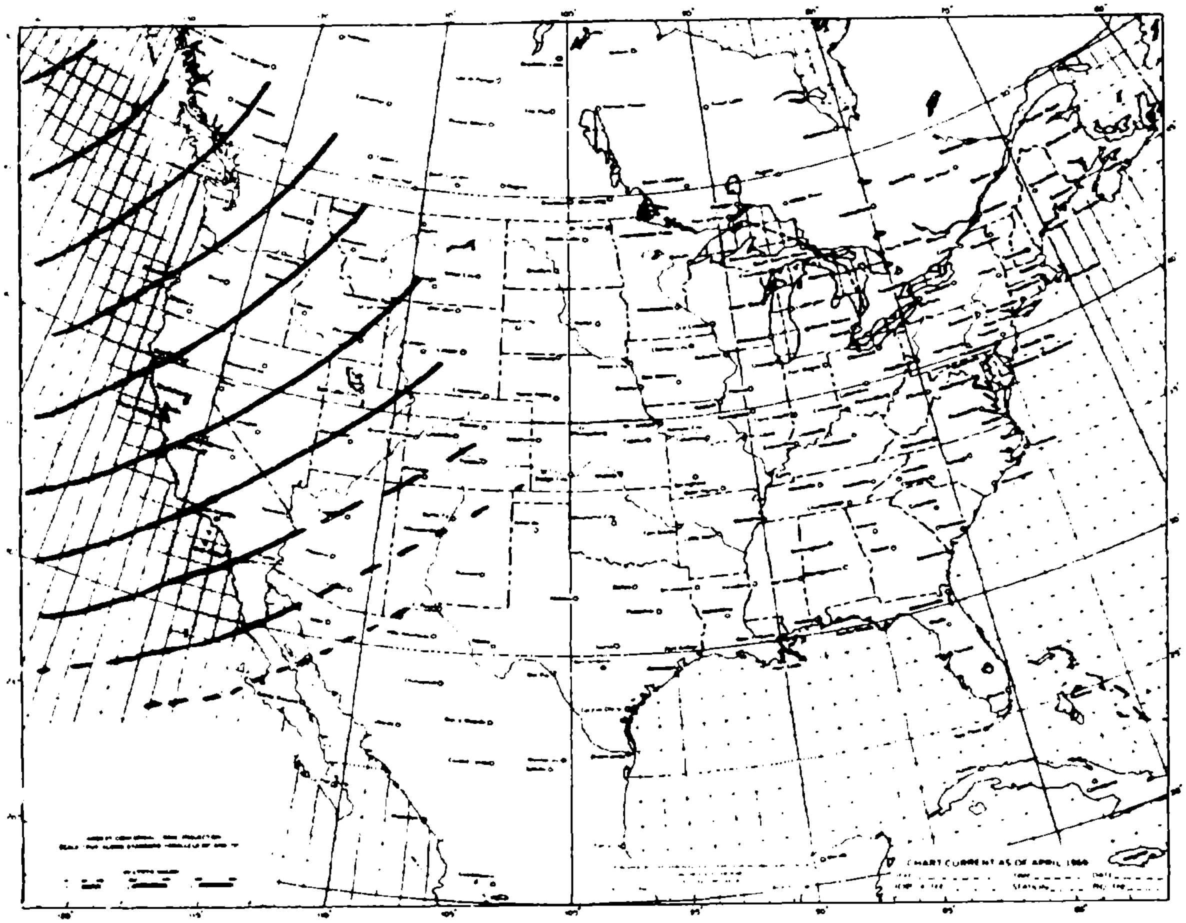

Figure 7-4. Preferred Paths of Dry Fronts Traversing Coastal Southern California.

(a) Summer

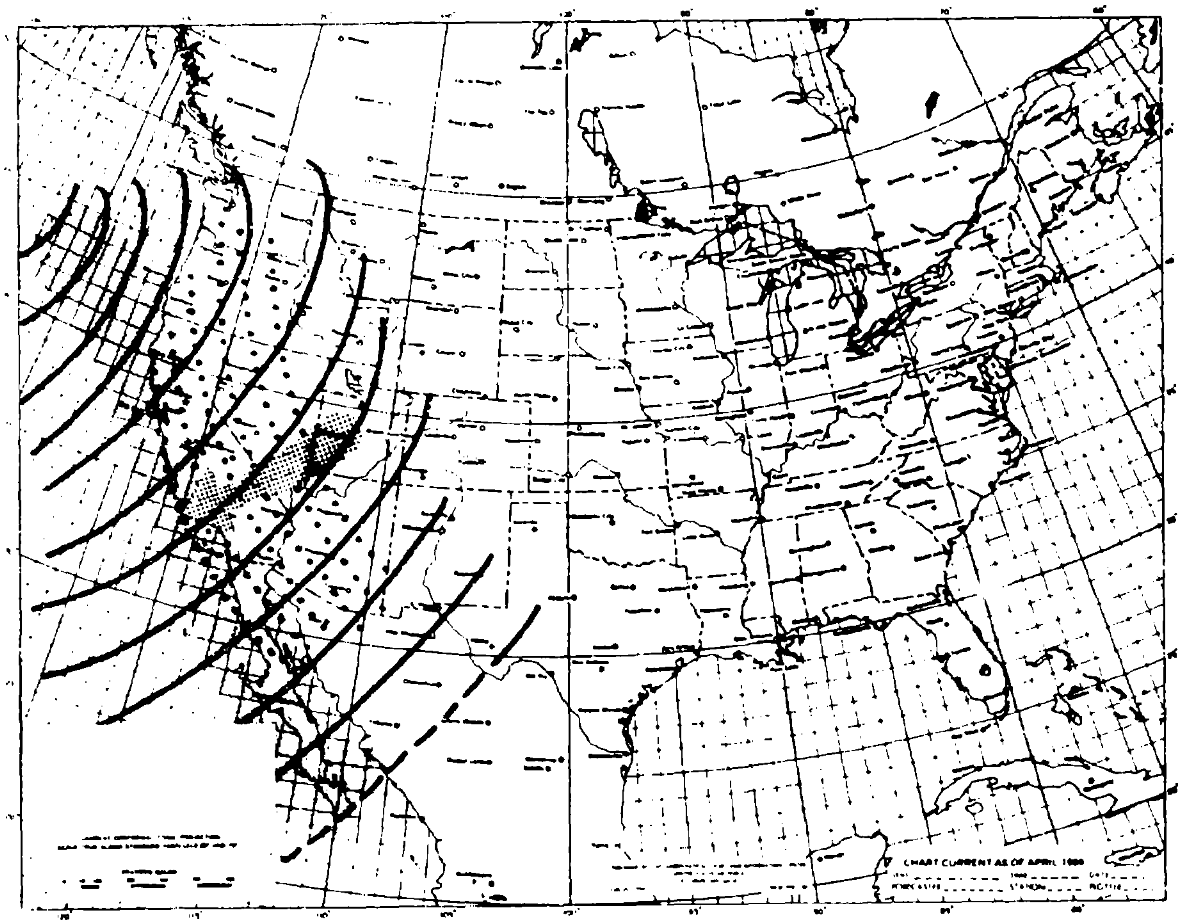

Figure 7-4. Concluded.

(b) Winter

initially active and wet, but dry out because of subsidence before reaching Point Mugu. A secondary preferred path of wintertime dry fronts is shown in figure 7-1(b) from the desert areas to the coast. These are the very few dry fronts which precede cold continental outbreaks and Santa Anas. Such fronts, moving contrary to the normal west-to-east movement of weather systems in our latitudes, seldom reach very far beyond the coastline before becoming stationary.

Speed of Movement

The most difficult task in determining the speed of movement of dry fronts is to locate the present position of the front. Because there is little of the cloudiness and frontal weather associated with the dry front that we see with more active ones, the forecaster must search for subtle clues such as rising pressure tendencies and wind shifts. When the front rides over a dense marine layer, such surface indications may not show up at all. In many cases, the best and perhaps only way of determining frontal position is by extrapolation.

Future positions must also be determined by extrapolation based upon educated guesses or estimates of how fast the front is moving and how fast it is likely to move. Observation of the speed of the upwind surface wind component normal to the front is useful in making these educated guesses. When it is strong, the front will move rapidly. If the flow behind the front is weak or nearly parallel to the front, slow frontal advancement should be expected. Individual forecasters will often have to rely on their own local analyses of surface conditions since National Meteorological Center surface maps frequently "drop" dry fronts from their analyses over the western states prematurely because these fronts are so lacking in conventional frontal characteristics when compared with fronts experienced over more eastern states. Nevertheless, these fronts have important effects on Point Mugu weather. In the absence of analyzed fronts on National Meteorological Center analyses, forecasters should be cautioned against pinpointing frontal positions to the location of the upper trough. Weak upper troughs sometimes move more rapidly and pass the surface front beneath it; this condition seems to be particularly associated with dry fronts at Point Mugu. As a general guideline, a front progressing at the rate of 200 miles or less per day may be considered slow; one progressing at a rate of more than 500 miles a day may be considered rapid.

Satellite Pictures and Vorticity

There are a few additional tools available to the forecaster in predicting the movement of, and weather associated with, dry fronts. One of these is satellite pictures which may photographically reveal the last remnants of middle or high clouds formerly associated with a weakening front. Or, if the front

is totally marked by a band of low clouds in the marine layer, satellite pictures may prove very useful as was shown in figure 7-1.

Another tool is vorticity. The properties and additional applications of vorticity are explained in more detail in appendix A and in other appropriate sections to follow. As concerns dry fronts, and particularly the most frequent case with movement from northwest to southeast, vorticity can be used to simply locate the associated upper trough and give some indication of the intensity and geographical extent of the system. For instance, in figure 7-5, a tongue of vorticity is seen extending from northern California down to offshore of Point Conception. The trough in the "08" vorticity contour indicates that the disturbance reaches that far south but the weakness of the vorticity gradient over southern California indicates that the frontal zone in that area is very inactive.

Other Weather Signs and Aids

Some changes in sky conditions may be interpreted as tentative "weather signs" of a dry front approaching Point Mugu although they may well precede any type of advancing front or disturbance. In summer, a rise of about 2,000 feet in the height of the inversion and base of stratus clouds often indicates the prefrontal increase in the depth of the marine layer. In winter, the approach of cirrus clouds from the west without appreciable midclouds or cumulus is a good sign of an advancing dry front.

FIGURE 7-5

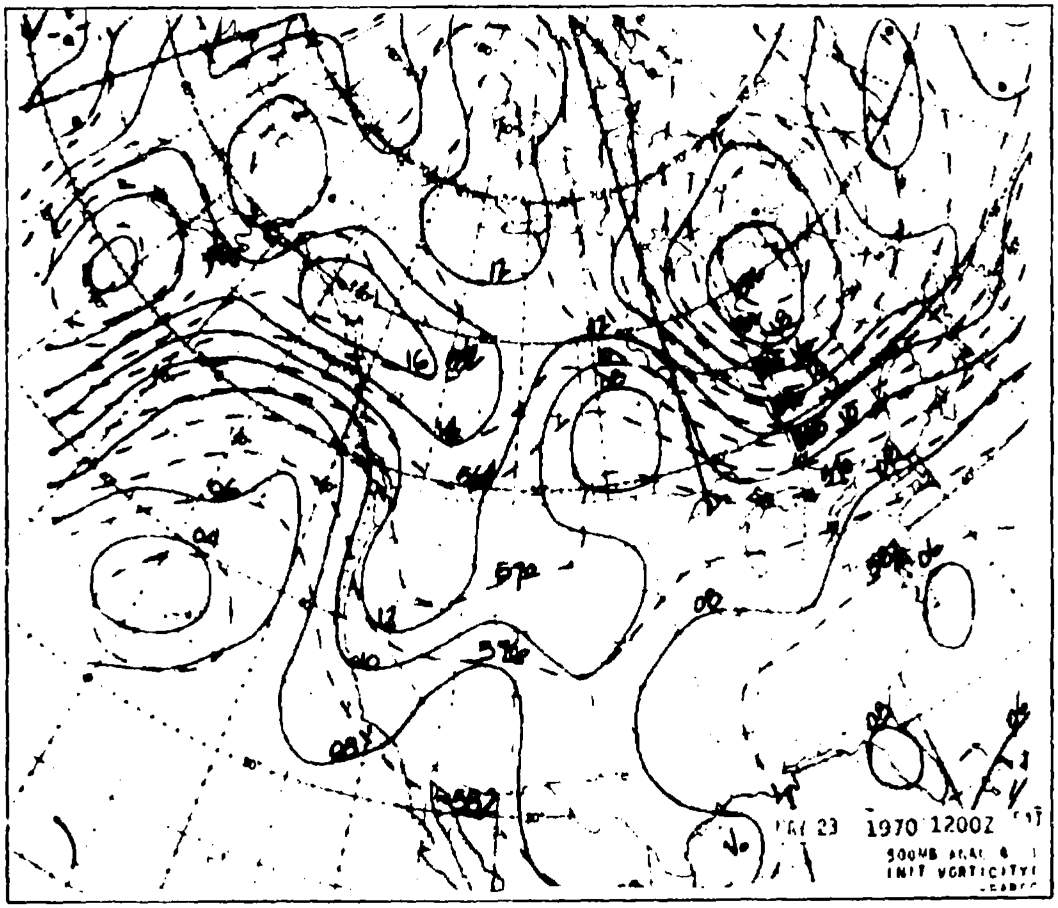

Figure 7-5. National Meteorological Center Vorticity Analysis of 1200 Z, 23 May 1970, Showing Vorticity Trough Related to Dry Front at Surface.

THUMB RULES AND FORECASTING AIDS ON DRY FRONTS

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
The great majority of fronts passing Point Mugu are dry.	\			7-3
Fast-moving fronts usually do not slow down appreciably before reaching Point Mugu.		\		*
Slow-moving fronts often "hang up" or dissipate in the mountains north of Point Mugu.		\		*
The approach of fronts causes the inversion to rise.	\			7-3
95% of Point Mugu's annual rainfall occurs from November to April from migratory lows and fronts from the Pacific.	\			7-11
Dry fronts often cause only a lifting of stratus.	\			7-9
Dry fronts often are not detectable when they ride over the marine layer.		\		7-14
Pressure tendencies and wind shifts may be the best clues as to the position of dry fronts.	\			7-14
Strong westerly winds and turbulence follow fast-moving dry fronts.		\		7-9
Santa Anas often follow dry fronts in the wintertime.	\			7-9

*See chapter 8

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Pressure	8-17
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Temperature	8-25
Pressure	8-25
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CHAPTER 8

DESCRIPTIONS

When the strong westerlies aloft dip far south in large amplitude troughs, and surface cold air is advected over the waters west of Point Mugu, cold fronts are active. As southerly winds aloft pump moisture into the cold unstable atmoshpere at middle levels, the surface cold air advances, forcing the air ahead of it to rise. This upward motion, together with orographic lifting as the front approaches the mainland, produces heavy clouds and precipitation along the coast and over the mountains. Convergence of air into the low-pressure center at the surface produces further upward motion that sustains the cloudiness and rain over an area much larger than that bounding the front. Strong winds often accompany the frontal weather both ahead of and behind the front. The surface front itself, however, is usually located close to the rear edge of the frontal cloud band.

Figure 8-1 shows a classic active front as seen by an ESSA 8 satellite. From the spiral-clouded low center at the top of the figure, the well-defined frontal band extends more than 1,000 miles. Characteristic

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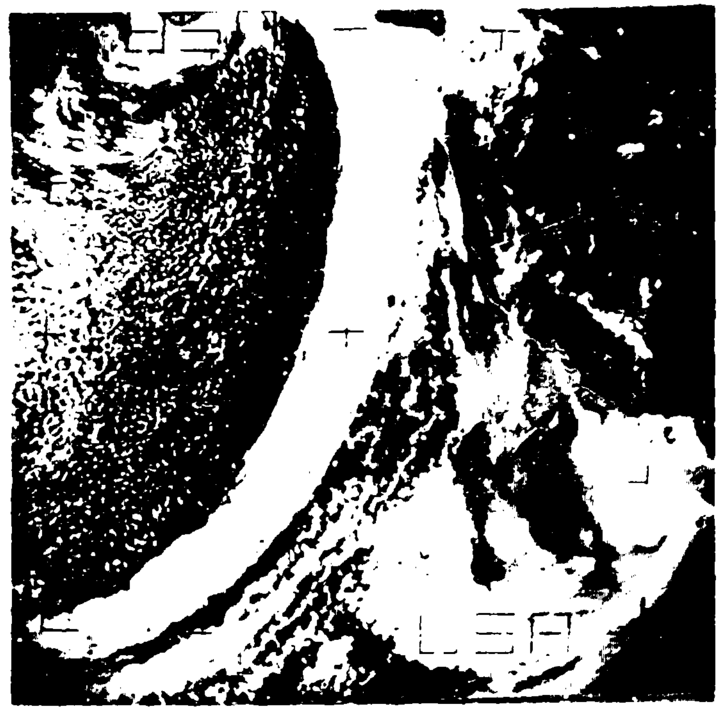


Figure 8-1. Active Front by ESSA 8, 21 April 1969, 1819 - 1839Z.

cellular cumulus clouds grow in the cold air after the initial postfrontal clearing. This active front lost much of its identity the day after it was photographed and only a little rain fell at Point Mugu. When the photograph was taken, however, all major features of active-front cloud structure were clearly visible.

Many frontal systems weaken as they approach Point Mugu, and although they may retain enough of their former characteristics to produce heavy rain (figure 8-1), the strong winds and other typical features often disappear. In other rain-producing situations very heavy rain may occur, but frontal zones are not identifiable. Thus, for simplicity, an active front will be defined as one strong enough to maintain cloud, rain, and wind characteristics when it passes Point Mugu. Occasional warm fronts and other rain-producing systems are discussed in Part II of this report.

A satellite picture of another active front (12 March 1968) is shown in figure 8-2. Although not so well defined pictorially as the previous example, this front produced over 0.50 inch of rain in approximately 4 hours the following day. An analysis of surface conditions just after frontal passage at Point Mugu is given in figure 8-3, and the detailed WBAN surface observations for Point Mugu are presented in figure 8-4, showing rainfall, wind, and cloud characteristics of an active front.

As an additional reference for the following discussions on active fronts, an especially wet and active one (20 January 1962) is illustrated in figure 8-5. In this example, Point Mugu experienced 1.56 inches of rain and 25-knot winds both ahead of and behind the front. The detailed WBAN

Figure 8-2. Active Front by Satellite, 12 March 1968.

surface observations for that day are presented as figure 8-6.

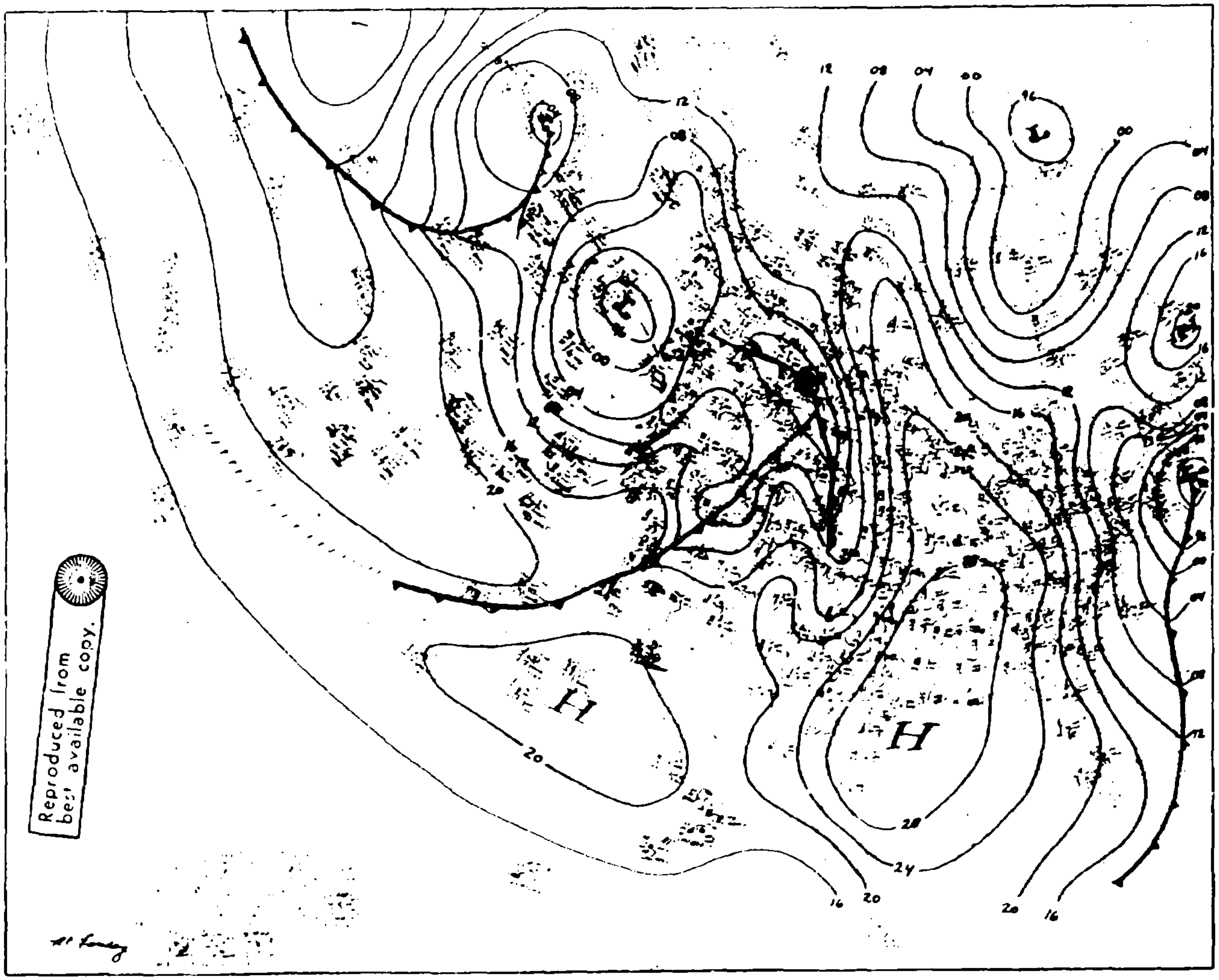


Figure 8-3. Surface Map of 1800Z, 13 March 1968.

FIGURE 8–4

OPNAV FORM 3140-6 (REV. 8-61)

WBAN FORM 10A

DEPARTMENT OF THE NAVY
SURFACE WEATHER OBSERVATIONS
(LAND STATIONS)

Station: PMR POINT MUGU, CALIFORNIA

Date: 13 MARCH 1968

S	0035	8⦶E25⦶120⦶	10					05	03				OP
R	0057	8⦶E25⦶	10		186	49	45	00	00		007	(B12 1800	RWM
R	0157	8⦶E25 ⦶	5	H	176	49	46	04	03		004		DP
R	0257	10⦶E25⦶	5	H	190	49	47	05	04		008		RWM
RS	0357	10⦶25⦶	5	H	173	47	45	05	04		003	815 1800 47	RWM
RS	0457	10⦶E25⦶	5	H	159	56	53	13	08		999		RMI
RS	0557	25⦶E30⦶	5	H	156	55	52	15	12	G18	998		DP
RS	0657	5⦶E25⦶80⊕	1	R-	166	55	52	16	08		001	RB19 505 172/HRLY PCPN .02	JT
S	0715	5⦶M15⦶80⊕	1	R				17	08				MJ
RS	0757	M4⦶15⊕	1½	R	169	52	52	36	05		002	HRLY PCPN .16	JT
RS	0857	M4⦶15⊕	4	R-F	173	54	52	05	02		003	HRLY PCPN .26	MJ
S	0920	5⦶E30⦶70⊕	4	R-F				06	04				MB
R	0957	6⦶E28⦶70⊕	4	R-F	180	55	54	05	05		005	31252 172/46 HRLY PCPN .08	TS
RS	1057	6⦶E35⦶100⊕	10		176	53	52	25	05		004	RE40 HRLY PCPN .03	TS
RS	1157	8⦶E12⦶35⦶100⊕	10		176	54	53	24	07		004	BB59E20 HRLY PCPN TRACE	TS
RS	1257	12⦶E25⦶100⦶	10		169	56	53	24	05		002	708 1510	MJ
RS	1357	12⦶25⦶	15		169	57	53	23	06		002		JT
R	1457	12⦶25⦶	15		169	58	52	28	09		002		MJ
R	1557	17⦶/⦶	15		169	58	51	28	12		002	TCU NE 80203 1402 513	TS
R	1657	17⦶U⦶	15		169	57	52	30	10	G15	002		TS
R	1757	17⦶80⦶4⦶	10		169	55	50	30	10	G15	002		MJ
R	1857	800U⦶	10		183	54	50	30	07		003	303 1028	FC
R	1957	50⦶800/-⦶	10		180	53	49	30	12		005		PMI
R	2057	50⦶800/-⦶	10		183	52	51	33	04		006		DP
R	2157	800U⦶	10		186	52	50	30	10		007	215 1028 58	DP
R	2257	/-⦶	10		190	51	50	31	03		008		DP
R	2357	/-⦶	10		190	51	48	29	10		008		FC

Figure 8-4. WBAN Surface Hourly Reports for Point Mugu, 13 March 1968.

OPNAV FORM 3140-7 (4-65)

DEPARTMENT OF THE NAVY
SURFACE WEATHER OBSERVATIONS
(LAND STATIONS)

PMR POINT MUGU, CALIFORNIA 13 MARCH 1968

TIME (LST)	STATION PRES SURE (Ins)	DRY BULB (°F)	WET BULB (°F)	REL HUMIDITY																	PRESSURE			HRLY PCPN
0057	30.070	49	47	86	9	3	Sc	8	6	Cu	E25	9	0			9	0			9	6	.035		
0157	30.040	49	47	89	8															8				
0257	30.080	49	48	93	7															7				
0357	30.025	47	46	93	5	1	Sc	10	4	Cu	25	5	0			5	0			5	8	.045		
0457	29.985*	56.2	54.2	88	9															8				
0557	29.980*	55	53	90	9															8				
0657	30.010	55	53	90	10	2	SF	5	5	ST	E25	7	3	NS	80	10	U			10	5	.015		.02
0757	30.020	52	52	100	10															10				.16
0857	30.030	53.8	53.0	95	10															10				.26
0957	30.045	54.5	54.0	97	10	3	SF	6	4	SC	E28	7	3	AS	70	10	U			10	3	.035		.08
1057	30.035	53	52	96	10															10				.03
1157	30.035	54	53	96	10															10				T
1257	30.020	56	54	90	8	2	SC	12	5	SC	E25	7	1	AS	100	9	0			6	7	.025		
1357	30.020	57	55	86	3															3				
1457	30.[illegible]20	58	55	80	5															5				
1557	30.015	58	54	77	4	3	Sc	17	1	Ci		4	0			4	0			4	8	.005		
1657	30.015	57	54	83	6															5				
1757	30.020	55	52	83	8															5				
1857	30.025	54	52	86	9	3	Ac	80	6	Cs	U	9	0			9	0			6	3	.010		
1957	30.045	53	51	86	8															3				
2057	30.060	52	51	96	6															2				
2157	30.070	52	51	93	8	3	Ac	80	5	Cs	U	8	0			8	0			5	2	.045		
2257	30.080	51	50	96	5															2				
2357	30.080	51	49	89	3															1				

Figure 8-4 Continued.

FIGURE 8-4

SYNOPTIC OBSERVATIONS

TIME (GCT) 41	TIME (LST) 42	NO 43	PRECIP (Ins) 44	SNOW FALL (Ins) 45	SNOW DEPTH (Ins) 46	MAX TEMP (°F) 47	MIN TEMP (°F) 48	49	STATE OF GROUND 50	SEA STATE & DIR 51	52	SWELL PER 53	54	WATER TEMP 55	56	57	58
	0357		0	0		50	47										
	0352	1	0	0	0	56	47							52.0			
	0957	2	52	0	0	56	46							57.6			
	1557	3	03	0	0	58	51							57.9			
	2157	4	0	0	0	58	52							57.4			
			0	0	0	52	51										

STATION PRESSURE COMPUTATIONS

59	0350	0950	1550	2150
60	770	750	750	765
61	30.172	30.186	30.156	30.214
62	-.145	-.140	-.140	-.144
63	30.027	30.046	30.016	30.070
64	1016.4	1017.0	1016.4	1018.0
65	+04	+04	0	+02

SUMMARY OF DAY

24 HR MAX TEMP (°F) 66	24 HR MIN TEMP (°F) 67	24 HR PRECIP WATER EQ. (Ins) 68	24 HR SNOWFALL (Ins) 69	SNOW DEPTH (Ins) 70	PEAK WIND SPEED 71	DIR 72	TIME 73	74	75	76	77	78	79	80	81
58	46	.55	0	0	19	WNW	1929					8	8		

KNOTS

PRECIP AND THUNDER 82	BEGAN 83	ENDED 84	SECTOR 85	BEGAN 86	ENDED 87
R-	0619	0705	H	0124	0020
R	0705	0857	F	0810	1057
R-	0857	1040			
RW-	1059	1129			

NOTE: There are no required entries in columns without headings. Any data needed locally may be entered.

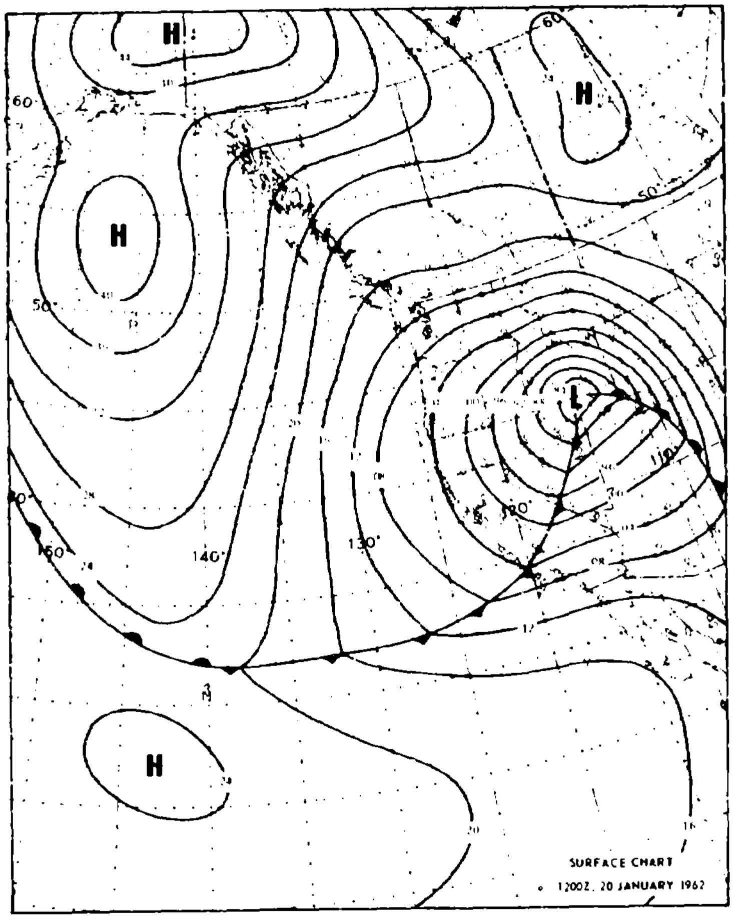
* 0445 PST SHIFTED FROM GMQ-14B TO LIQUID IN GLASS THERMOMETER

* 0545 PST SHIFTED FROM LIQUID IN GLASS THERMOMETER TO GMQ-14B

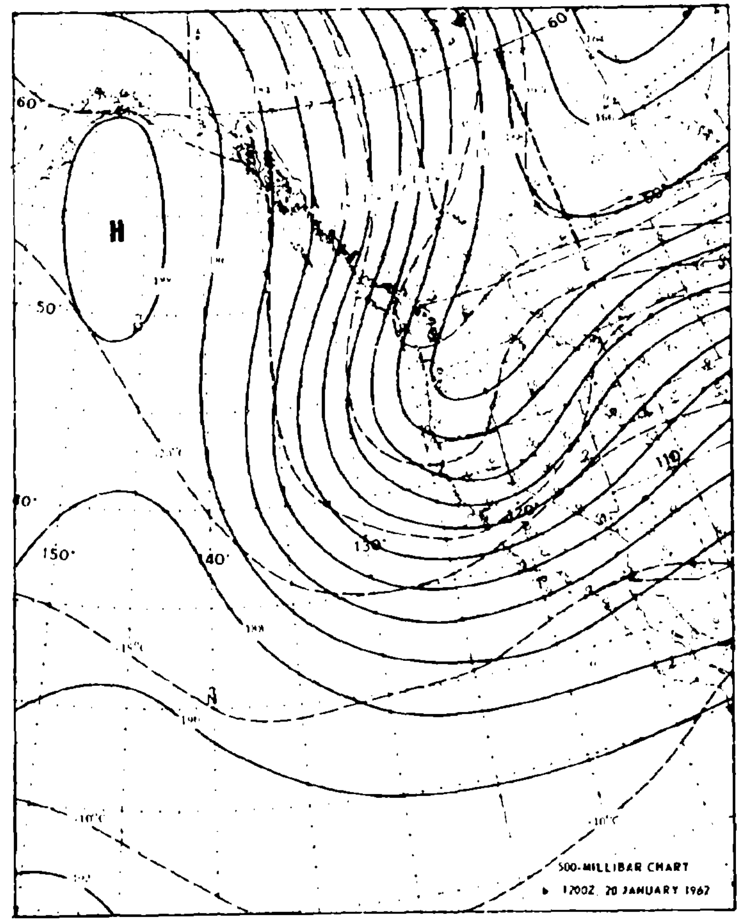
* 0820 PST SHIFTED FROM GMQ-14B TO LIQUID IN GLASS THERMOMETER

* 1010 PST SHIFTED FROM LIQUID IN GLASS THERMOMETER TO GMQ-14B

Figure 8-4. Concluded.



(a) Surface Analysis of 1200Z, 20 January 1962.



(b) 500-Millibar Analysis of 1200Z, 20 January 1962.

Figure 8-5. Upper Trough Associated With Active Surface Front.

FIGURE 8-6

OPNAV FORM 3140-6 (REV. 8-61) 0107-711-6900 WBAN FORM 10A

DEPARTMENT OF THE NAVY
SURFACE WEATHER OBSERVATIONS
(LAND STATIONS)

Station: PMR POINT MUGU, CALIFORNIA

Date: 20 JANUARY 1962

Type (1)	Time (LST) (2)	Sky and ceiling (Hundreds of feet) (3)	Visibility (Statute miles) Surface (4)	Visibility Tower (4a)	Weather and obstructions to vision (5)	Sea level press. (mbs.) (6)	Temp. (°F) (7)	Dew pt. (°F) (8)	Wind Direction (9)	Wind Speed (10)	Wind Character (11)	Altimeter setting (ins.) (12)	Remarks and supplemental coded data (13)	Observer's initials (15)
L	0010	M29⊕	10		R--								(ECSTR)	NH
✓	0039	M30⊕	8		R--				↑↖	8		991	BINOVC OVHD	NH
L	0040	M26⊕	8		R-								(FCSTR)	NH
R	0057	15Φ M20⊕	8		R-	129	51	50	↑↖	5		990	RB10 820-15XX	NH
S	0115	M10⊕	4		R				↑↖	8			VSBY E2	NH
✓	0130	M10Φ25⊕	4		R-				↑↖	8		989	R- OCNL R	NH
R	0157	M10Φ25⊕	4		R-	123	51	50	↑↖	8		988	R- OCNL R	NH
S	0210	10ΦM18Φ	5		R--				↑↖	8			(FIBI)	NH
S	0219	14ΦM20⊕	5		R--				↑↖	13				NH
✓	0229	14ΦM20⊕	5		R--				↑↖	10		987		NH
S	0245	14ΦM20⊕	4		R--				↑↖	12			R-- OCNL R-(FIBI)	NH
R	0257	14ΦM20⊕	4		R--	111	52	50	↑↗	13		985	R-- OCNL R-	NH
L	0315	14ΦM20⊕	4		R--								(FCSTR)	BS
S	0320	14ΦM20⊕	7						↑↗	13				NH
✓	0330	10ΦM20⊕	7						↑	9		983		NH
RS	0357	14ΦM31⊕	7			100	52	50	↖	13		981	RE20 82912 15XX51 11171 INTER	NH
													085 16 G35 GRADU 25828 1/131	NH
MD	000	81313	616	25	10052	6	55	XX	50B	29	7	12D	0	
S	0415	W5X	2		R+				↖	13	+20			NH
✓	0429	W5X	2		R+				↑	15	+22	980		NH
R	0457	W5X	2		R+	092	51	51	↑↗	15	+25	979	RB15	NH
L	0512	W5X	2		R+									NH
S	0526	W5X6⊕	2		R				↑↗	17	+23	978		NH
L	0538	W5X	2		R+									NH
R	0557	W5X	2		R	085	51	51	↑	15	+25	977		NH
L	0612	W5X	2		R									NH

Figure 8-6. WBAN Surface Hourly Reports for Point Mugu, 20 January 1962.

A synoptic observation, in WMO code format (MIIIA), is entered on line following related area

S	0630	E 6 ⊕	2		R				↖	15			NH
R	0657	E 6 ⊕	2		R	073	52	52	↑ ↖	15 + 21	973	827 17XX	NH
S	0700	W 4 X	1½		RF				↑ ↖	15 + 25			NH
S	0704	W 4 X	¾		RF				↖	15 + 24			NH
RS	0757	W 3 ⊕	¾		RF	062	52	52	↑ ↖	10	970		BS
RS	0857	E 2 ⊕	½		RF	060	55	55	↑ ↗	15 + 25	970		BS
S	0910	E 3 ⊕	5		R				↑ ↗	16			BS
R	0957	E 3 ⊕	5		R	057	55	55	↑	15 + 25	969	6154/12ANE 17XX 5L 108 48	
												INTER 052/B Gradu 20838	
												11151	BS
WID	000	81815 586	16	057	5505787	2XX		55	6185	74170	ONE		
RS	1057	8 Φ E 60 ⊕	5		R	052	55	55	↗	14	967		BS
RS	1157	8 Φ E 30 Φ 65 ⊕	5		R	042	55	55	↗	15 + 20	964		BS
V	1228	8 Φ E 30 Φ 65 ⊕	5		R				↗ ↗	15	964		CR
R	1257	8 Φ E 30 ⊕	7			034	55	55	→ ↗	15	957	RE45 624021500 1500	CR
RS	1357	8 Φ 30 Φ E 65 ⊕	7			034	55	49	→ ↗	15 + 20	962		BS
V	1430	8 Φ 40 Φ / - Φ	10						↗ ↗	24		APRNT EROPA	BS
R	1457	15 Φ 40 Φ / Φ	15			034	55	49	→	25	962		BS
V	1530	40 Φ	15						→	20	961		BS
R	1557	40 Φ / Φ	15			030	54	47	→	20	961	80503 13/01.55 1119/1131	BS
WID	000	12720 74	016	0	3054	136	01	4	7805	71840			
V	1630	40 Φ / Φ	15						→	15	961		BS
R	1657	40 Φ / Φ	15+			028	53	45	→	20	960		BS
V	1730	40 Φ	15+						→	15	960		BS
R	1757	40 Φ	15+			028	52	44	→	18 + 26	960		BS
V	1830	O	15+						→	20	960	CU SW	BS
R	1857	O	15+			035	52	44	→	20	962	30500 1300	BS

OP 0087

Figure 8-6. Continued.

FIGURE 8-6

OPNAV FORM 3140-6 (REV. 8-61)

DEPARTMENT OF THE NAVY
SURFACE WEATHER OBSERVATIONS
(LAND STATIONS)

PMR POINT MUGU, CALIFORNIA
20 JANUARY 1962

V	1929	O	15+							20	963		NH
R	1957	O	15+			039	51	44		20 ± 25	964	Cu NE CL NE	NH
V	2029	O	15+					39		14 + 22	964	Ac NE CL OVHD	NH
R	2057	O	15+			044	51	39		15 ± 21	965	Ac NE CL NE	NH
V	2129	O	15+							14 ± 21	966	Ac NW	NH
R	2157	100Φ	15+			049	49	36		15 + 22	966	215 107055 1191 1134	NH
MD	0000	12915	74030		04949	00930			36215				
V	2229	100Φ	15+							12 + 19	967		NH
L	2243	E120Φ	15+									(FCSTR)	NH
R	2257	E120Φ	15+			053	49	32		12	968		NH
V	2329	40ΦE120Φ	10							10	967		NH
RS	2357	40⊕	8		T	054	46	39		18	968	7B41 LTGCC-CG	NH

Figure 8-6. Continued.

FIGURE 8-6

OPNAV FORM 3140-7 (4-65)
0107-711-1001

DEPARTMENT OF THE NAVY
SURFACE WEATHER OBSERVATIONS
(LAND STATIONS)

WHAS 10B

STATION PMR POINT MUGU, CALIFORNIA DATE 20 JANUARY 1962

TIME (LST)	STATION PRES-SURE (Ins)	DRY BULB (°F)	WET BULB (°F)	REL HUMIDITY																TOTAL OPAQUE SKY COVER	PRESSURE	NET 3-HR CHANGE		
16	17	18	19	20	21																		39	40
0057	29.900	51.1	50.4	95	10	2	SF	15	8	SC	M20	10	u				u			10	8	.060		T
0157	29.880	51.2	50.8	98	10	6	SF	M10	4	SC	25	10	u				u			10				.04
0257	29.845	51.9	51.0	94	10	5	SF	14	5	SC	M20	10	u				u			10				.05
0357	29.815	51.8	50.8	94	10	3	SF	18	7	SC	M31	10	u				u			10	8	.085		.03
0457	29.790	51.3	51.3	100	10	10	RT	W5	u				u				u			10				.18
0557	29.770	51.0	51.0	100	10	10	RT	W5	u				u				u			10				.24
0657	29.735	51.6	51.6	100	10	10	SF	E6	u				u				u			10	8	.080		.27
0757	29.700	52.0	52.0	100	10	10	SF	E3	u				u				u			10				.42
0857	29.695	54.8	54.8	100	10	10	SF	E2	u				u				u			10				.15
0957	29.680	55.1	55.1	100	10	10	SF	E3	u				u				u			10	6	.045		.15
1057	29.675	55.4	55.4	100	10	4	SF	8	6	SC	E50	10	u				u			10				.03
1157	29.645	55.4	55.4	100	10	2	SF	8	7	SC	E30	9	1	AC	65	10	u			10				T
1257	29.620	55.3	55.3	100	8	1	SF	8	7	SC	E30	8	0			8	0			8	6	.070		T
1357	29.620	54.5	51.5	82	7	1	SF	10	4	SC	30	5	2	AC	E65	7	0			7				
1457	29.620	54.5	51.5	82	3	2	SC	15	1	CU	40	2	1	CI	/	3	0			2				
1557	29.605	54.0	50.0	76	2	1	CU	40	0	CI	/		0				0			1	8	.015		
1657	29.600	53.0	49.0	75	2	1	CU	40	1	CI	/	2	0			2	0			2				
1757	29.600	52.0	48.0	75	1	1	CU	40	0			1	0			1	0			1				
1857	29.620	52.0	48.0	75	0	0	CU	40	0			0	0			0	0			0	3	.015		
1957	29.639	50.9	46.0	69	0	0	CU	40	0	CI	/	0	0			0	0			0				
2057	29.650	50.5	45.0	65	0	0	AC	45	0	CI	/	0	0			0	0			0				
2157	29.665	49.3	43.1	59	0	0	AC	100	0			1	0			1	0			1	2	.045		
2257	29.675	49.0	43.4	63	7	7	AC	E120	0			7	0			7	0			6				
2357	29.680	49.5	44.4	66	10	10	SC	M42	0				u				u			10				

Figure 8-6. Continued.

FIGURE 8-6

SYNOPTIC OBSERVATIONS

TIME (GCT) 41	TIME (LST) 42	NO. 43	PRECIP. (Ins) 44	SNOW FALL (Ins) 45	SNOW DEPTH (Ins) 46	MAX TEMP (°F) 47	MIN TEMP (°F) 48	49	STATE OF GRND 50	SEA STATE & DIR 51	SWELL HGT & DIR 52	SWELL PERIOD 53	SURF Hs Hs M,P,S,D,S 54	WATER TEMP 55	56	57	58
	MID TO 0345	X	.12	0	X	53	51	X	X	X	X	X	X	X	X		
	0345	1	.12	0	0	54	51										
	0945	2	1.44	0	0	55	51										
	1550	3	.03	0	0	55	54										
	2145	4	0	0	0	54	49										
	MID	X	0	0	0	50	49	X	X	X	X	X	X	X	X		

STATION PRESSURE COMPUTATIONS

TIME (LST) 59	0350	0950	1550	2145
ATT THERM 60	74.5	75.0	78.0	76.0
OBSRVD BAR 61	29.866	29.842	29.768	29.820
TOTAL CORR 62	-.153	-.154	-.162	-.157
STA PRESS 63	29.863	[illegible]	29.606	29.663
BAROGRAPH 64	1009.4	1005.0	1002.2	1004.[illegible]
BAR CORR 65	+0.1	+0.3	+0.3	+0.1

SUMMARY OF DAY (MIDNIGHT TO MIDNIGHT)

24-HR MAX TEMP (°F) 66	24-HR MIN TEMP (°F) 67	24-HR PRECIP WATER EQUIV (Ins.) 68	24-HR SNOWFALL UNMLTD (Ins.) 69	SNOW DEPTH (Ins.) 70	PEAK GUSTS SPEED 71	PEAK GUSTS DIRECTION 72	PEAK GUSTS TIME (LST) 73	74	75	76	77	SKY COVER SUNRISE TO SUNSET 78	SKY COVER MIDNIGHT TO MIDNIGHT 79	80	81
55	49	1.56	0	0											

PRECIP AND THDRSTM 82	BEGAN 83	ENDED 84	OBSTR TO VISION 86	BEGAN 87	ENDED 88
R--	0010	0040	F	0659	0915
R-	0040	0115			
R	0115	0130			
R-	0130	0210			
R--	0210	0320			
R+	0415	0526			
R	0526	0538			
R+	0538	0550			
R	0550	0915			
R-	0915	0921			
R--	0921	1245			
T	2340	CONT.			

90 REMARKS, NOTES AND MISCELLANEOUS PHENOMENA

FASTEST RECORDED ONE MINUTE WIND SPEED	ASSOCIATED DIRECTION	TIME
KNOTS		

NOTE: There are no required entries in columns without headings. "Any data needed locally may be entered"

Figure 8-6. Concluded.

TYPICAL WEATHER ASSOCIATED WITH ACTIVE FRONTS

Sky Conditions

With the approach of an active front from the west or northwest, middle and high clouds usually thicken and lower, and low scattered stratocumulus clouds often form over the hills, developing vertically until they eventually obscure the mountains to the north. Formation of large cumuliform buildups over the water to the south and west indicate a large-scale rising motion attributable to the advancing storm and not to mountainous terrain or intense local heating. Thus, large cumulus buildups over the water are very often a good indication that rain will fall at Point Mugu regardless of whether any has already fallen in the recent past.

Even before the movement of thick frontal clouds into the area, a clear band may appear separating the pre-existing stratus and stratocumulus common to this area from the advancing higher and thicker clouds of the frontal band. This feature, which sometimes appears on satellite pictures, can result in a short period of surprisingly good weather. Part of one of these clear bands is visible in figure 8-1, just ahead of the southern portion of the front. See also figure 4-14 and chapter 4.

Visibility

With the approach of an active front, generally visibility first decreases as the low-level southeast flow advects smog and pollutants from the Los Angeles Basin and Santa Monica Bay into the local area. As a result, visibilities may be restricted to 4 or 5 miles from Los Angeles to Santa Barbara and northwest to Santa Maria. As the front approaches, upward motions and weakening and destruction of the inversion result in a mixing of the pollutants to cause greatly improved visibilities before the start of any precipitation.

Winds

With the approach of an active front, surface winds at Point Mugu are often light westerly or southerly at first, but become stronger and more consistently southeast as the front nears. The southeast wind is due to turning by coastal terrains of the predominantly southerly prefrontal winds over the open sea. Until this southeast wind begins, however, Point Mugu is still subject to the oscillations of the land- sea-breeze regime.

Pressure

With the approach of an active front, there is usually a slight but steady decrease in pressure superimposed upon the semidiurnal pressure oscillation.

Sea Conditions

Sea conditions with the approach of an active front depend mainly on the strength of the surface wind at the time in question. In addition to locally generated surf and sea conditions, westerly swell is sometimes observed also. These swells originate hundreds of miles out at sea in regions of strong persistent westerly winds just south of the main storm track.

San Nicolas Island and Sea Test Range

At San Nicolas Island and over the open waters of the Sea Test Range, strong southeast winds occur less often than at the coast. Seas are usually higher, though, particularly if there is a westerly swell. In all other respects, conditions with the approach of an active front are very similar to those observed for Point Mugu.

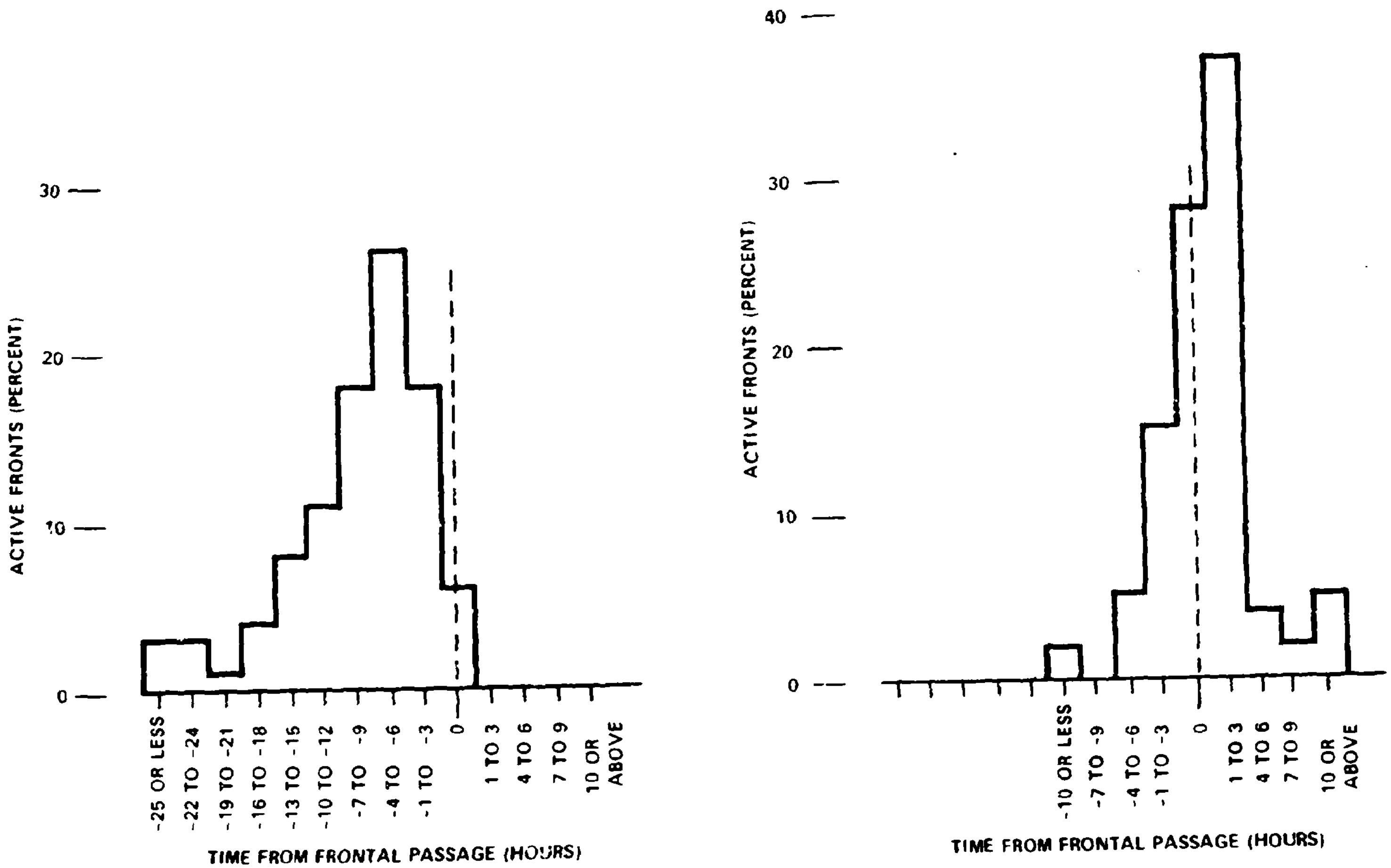
PREFRONTAL WEATHER

By the time the advancing front is within about 200 miles of Point Mugu and southern California coastal regions, the prefrontal region--where isobars are closely packed and oriented southwest-northeast--has usually reached the mainland (figures 8-3 and 8-5(a)). The dense frontal cloud band evident in figures 8-1 and 8-2 has also usually reached the local area with a variety of characteristic weather conditions, as summarized below.

Precipitation

About 6 hours before passage of the frontal cloud shield, rain begins to fall. It is usually continuous and ends near the time of frontal passage (figure 8-7). This precipitation is directly attributable to the upward motions that prevail ahead of the front and are orographically enhanced in the vicinity of the coastal mountains. Due to the orientation of the coastal mountains with respect to prefrontal wind directions, Point Mugu lies in a slight downwind "rain shadow" (reference 47 and figure 8-8), so that rainfall recorded at the station is not so heavy as along the nearby coastal slopes or other adjacent areas. Nevertheless, the precipitation typically produces about a half-inch of moderate or heavy rain, the heaviest usually occurring at frontal passage (figure 8-9). Climatologically, there is at least one report of moderate or heavy rain associated with 4 of every 5 active fronts. Hail, lightning, and thunder occasionally accompany the frontal cloud burst. The typical period of moderate and heavy frontal rainfall is well shown in the observations of the 20 January 1962 example (figure 8-6).

The patterns of rainfall described above are sometimes further modified by proximity of Point Mugu to changing regions of convergent winds near the surface or by overrunning of warm, moist air above a shallow surface layer of colder air. Thus, for a given storm or active front, total rainfall amounts vary greatly in Ventura County and coastal southern California (reference 48).



(a) Time of Onset of Continuous Precipitation (Reference 38).

(b) Time of End to Continuous Precipitation (Reference 38).

Figure 8-7. Precipitation Relative to Frontal Passage.

FIGURE 8-8

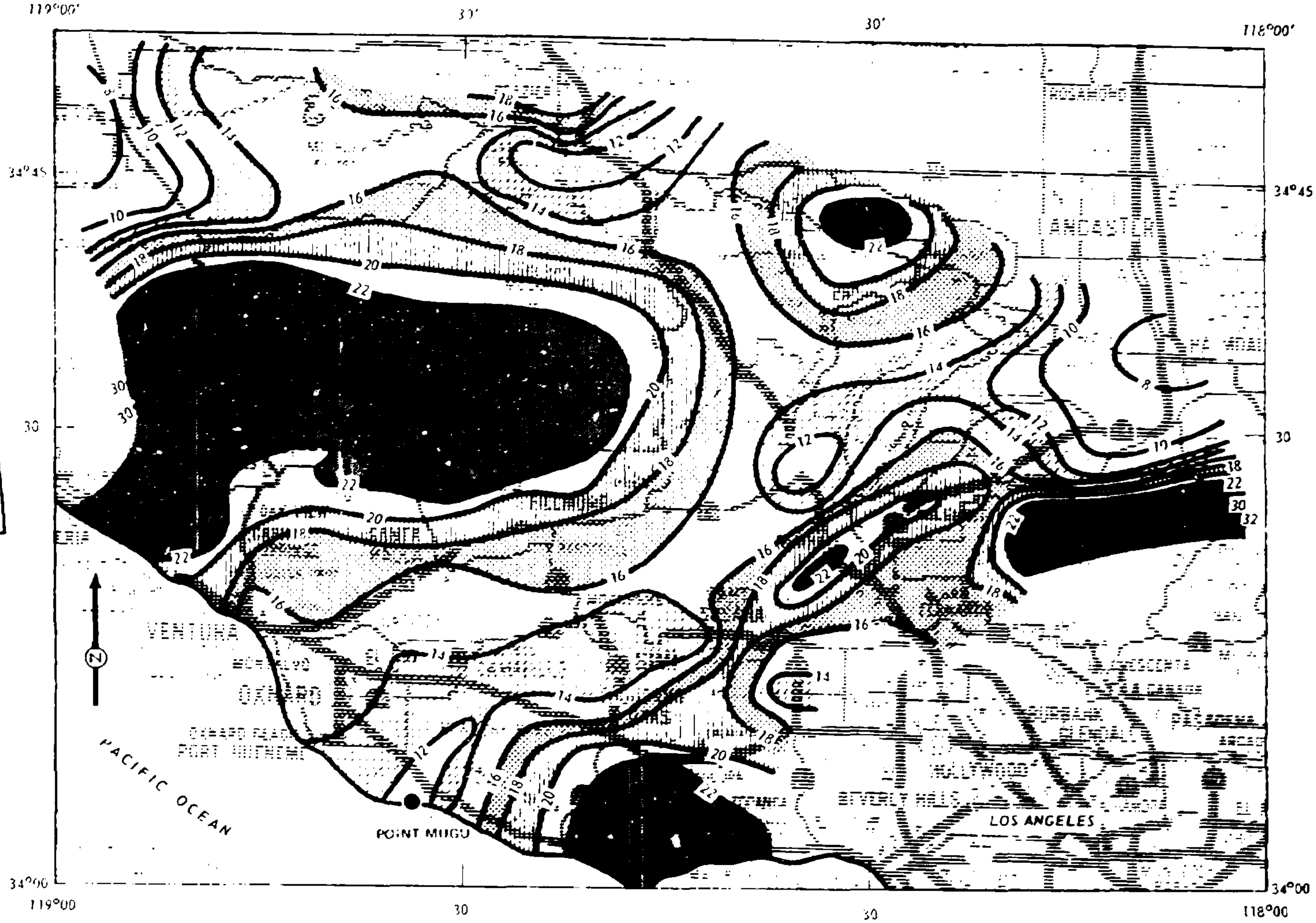


Figure 8-8. Mean Seasonal Precipitation, in Inches, for Local Area. Based on data from 1897-8 through 1946-7 (Reference 47).

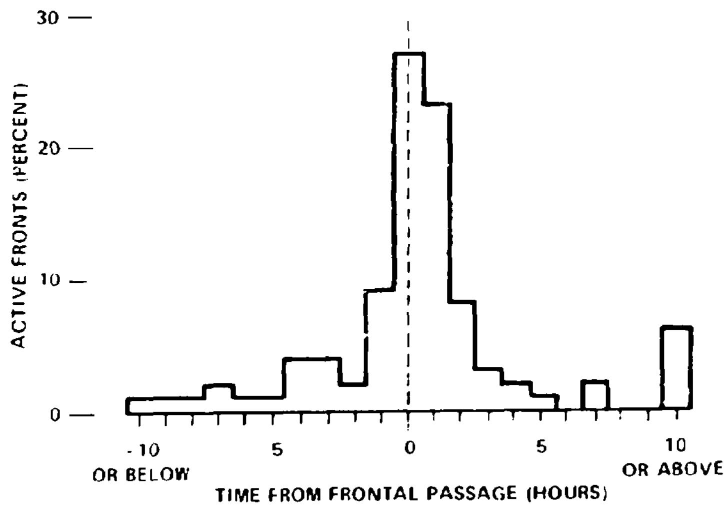


Figure 8-9. Time of Heaviest Precipitation Relative to Active Frontal Passage (Reference 38).

Sky Conditions

As the heavy frontal band shown in figures 8-1 and 8-2 moves onto the coast, a mid-cloud ceiling characteristically lowers to a low-cloud ceiling. In general, these low ceilings are about 900 feet but zero-zero conditions are occasionally experienced (reference 38). The lowest cloud elements are usually fractostratus, which form as cold rain falls from the higher nimbostratus, thereby cooling the near-saturated lower layers. This sometimes causes a rapid lowering of the ceiling (reference 49). The nimbostratus itself is difficult to observe owing to a combination of its lack of distinguishing characteristics and the low cloud cover, but it is almost always present if there is continuous precipitation. On the other hand, the fractostratus layer is easier to observe because of its extreme lowness. At the time of frontal passage, heavy squalls may reveal the presence of cumulonimbus clouds. Simultaneously, fractostratus ceilings are usually lowest: thus the cumulonimbus is usually not visible to the observer even if present.

Figure 8-10 shows the time of lowest ceiling relative to frontal passage based on statistical studies. As was noted for the time of heaviest precipitation, lowest ceilings occur most frequently at frontal passage. Characteristic cloud observations for the two examples of active fronts are shown in figures 8-4 and 8-6.

Visibility

Reduced visibility from rain and fog is another prominent feature of prefrontal weather associated with active fronts. On the average, lowest visibilities are 1 or 2 miles, but sometimes a combination of fog associated with the low ceilings and precipitation from the higher cloud deck will lower visibility to less than 1 mile. Lowest visibilities generally occur at the time of frontal passage (figure 8-11), which is consistent with the distribution of ceiling heights and rainfall intensities.

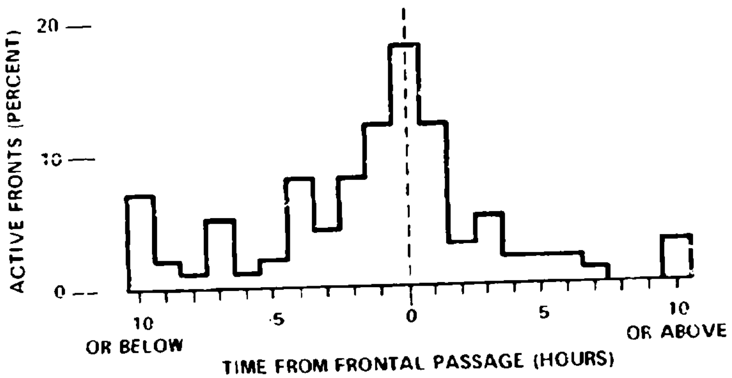


Figure 8-10. Time of Lowest Ceiling Relative to Active Frontal Passage (Reference 38).

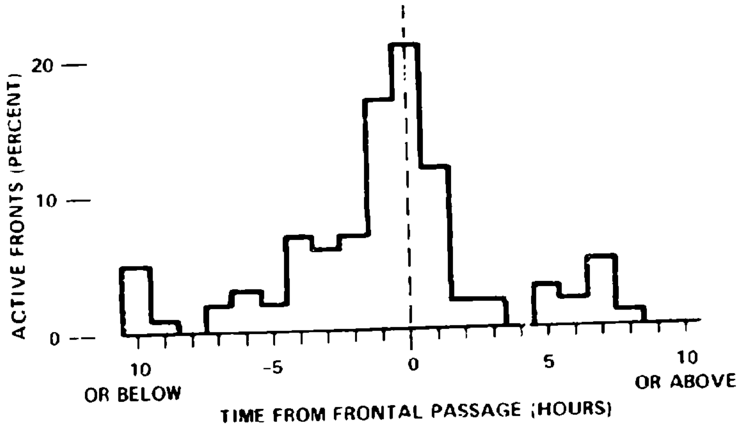
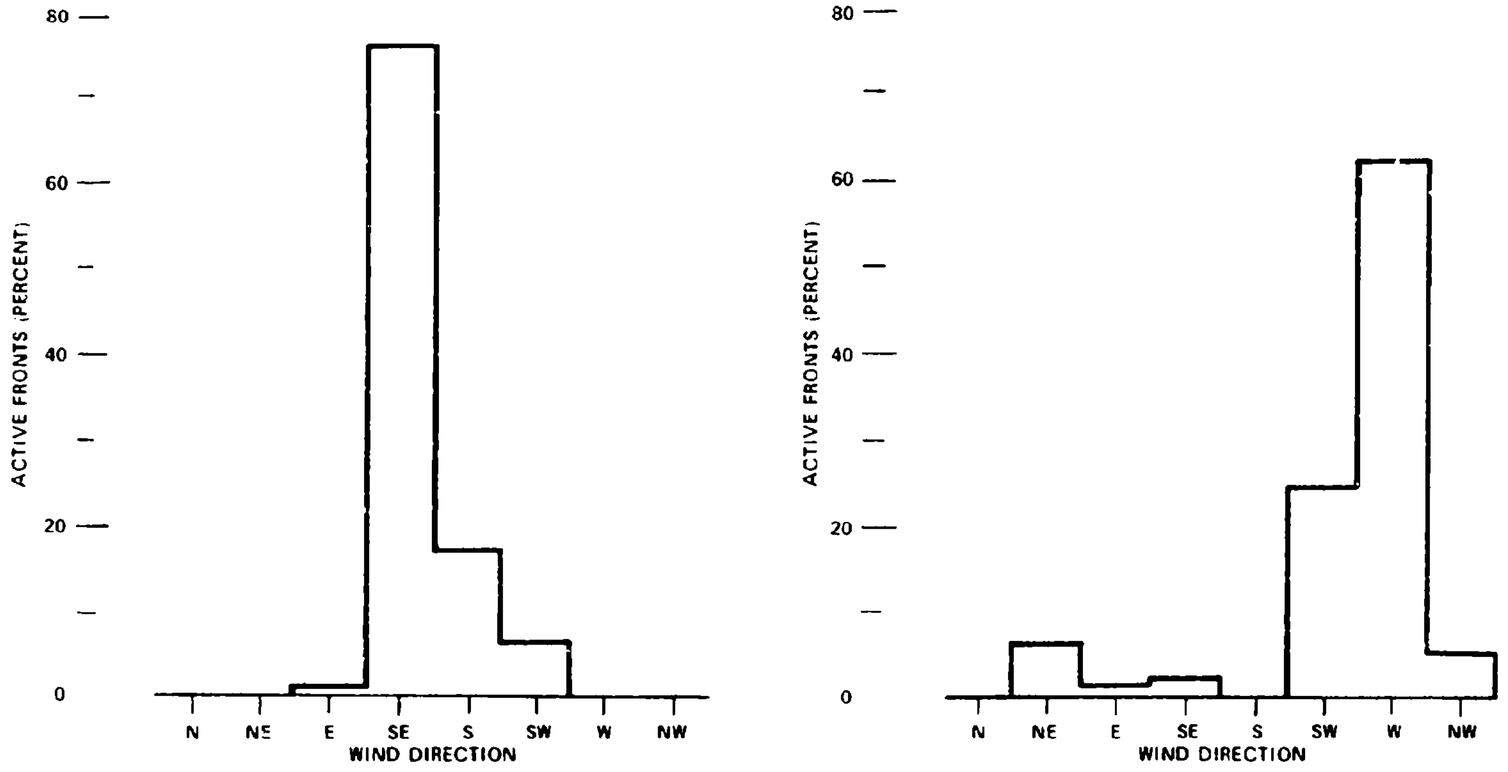


Figure 8-11. Time of Lowest Visibility Relative to Active Frontal Passage (Reference 38).

Winds

One of the most distinguishing characteristics of active prefrontal weather is the occurrence of strong southeast winds. In nearly 75% of active frontal cases, prefrontal winds are from the southeast, with most of the remaining 25% from the south and southwest. The reason for this predominently southeasterly direction is that coastal terrain restricts the airflow, forcing nearly any wind with a strong southerly component to be deflected along the southeast-northwest-oriented coastline. Because of the squeezing of the airflow against the mountains and the generally tight prefrontal pressure gradient, the southeast winds are fairly strong, frequently warranting wind warnings. Average speeds may be only about 15 knots, but gusts have reached 42 knots in recent years (since relocation of the AN/UMQ-5 to the runway in 1962). Frequencies of pre- and post-frontal directions and average and peak gust speeds are given in figures 8-12, 8-13, and 8-14.

On the average, the prefrontal southeasterlies begin about 10 hours before passage of the front, although they may occasionally begin as much as 4 days in advance. As the front approaches and the squeezing against the mountains continues, the speeds increase until they reach a maximum at or just before the time of frontal passage (figure 8-15). As the front passes, the winds veer abruptly to westerly, at the same time generally decreasing in strength.



(a) Prefrontal Winds.

(b) Postfrontal Winds.

Figure 8-12. Distribution of Average Wind Directions With Active Fronts (Reference 38).

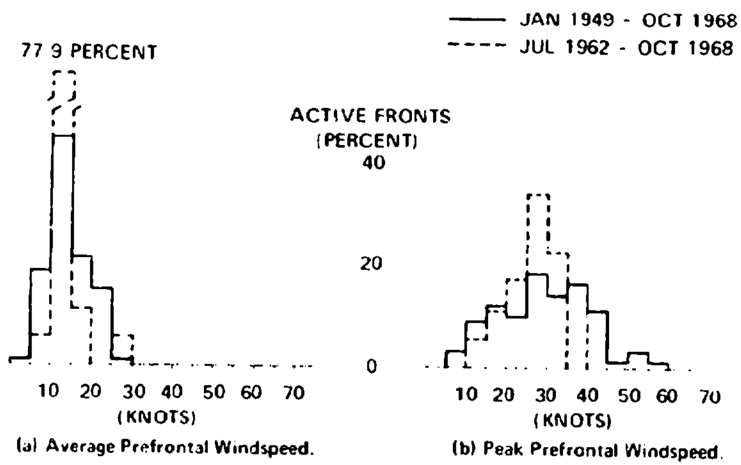


Figure 8-13. Distribution of Prefrontal Windspeeds With Active Fronts (Reference 38).

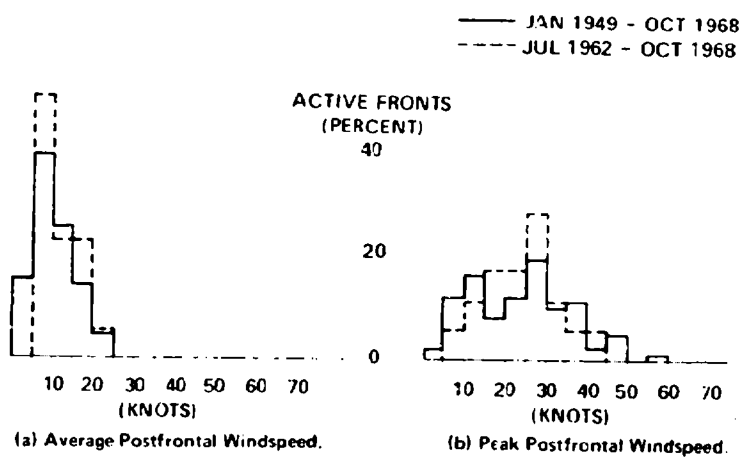


Figure 8-14. Distribution of Postfrontal Windspeeds With Active Fronts (Reference 38).

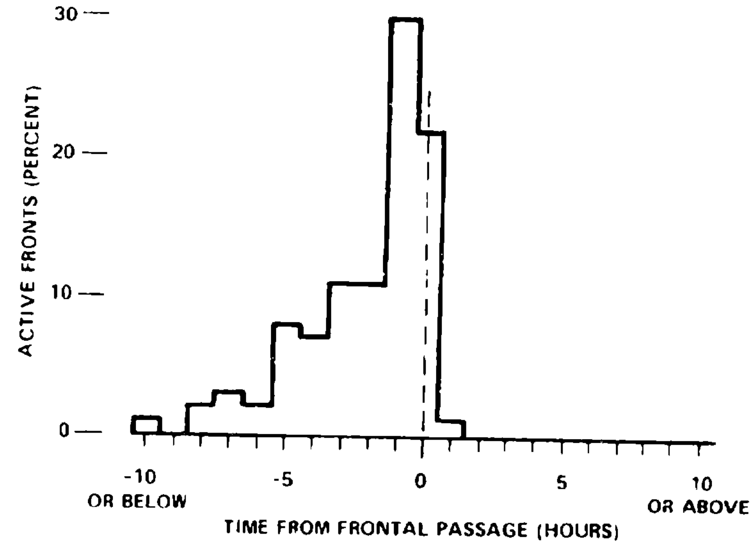


Figure 8-15. Time of Strongest Prefrontal Winds Relative to Active Frontal Passage (Reference 38).

Thus, prefrontal winds for active fronts at Point Mugu are usually stronger than postfrontal winds.

Freezing Level

Coincident with worsening weather conditions at the surface, the altitude of the freezing level usually begins to lower near frontal passage, and snow may occur down to or below the 5,000-foot level. The lowering of temperatures at these levels is a direct reflection of the approach of the cold trough aloft. Meanwhile, near the surface, the southeast winds

keep temperatures mild. The warmth below, when coupled with the cooling aloft, results in very unstable conditions near the front and probably aids in the production of heavy convective clouds and precipitation at the time of frontal passage.

Sea Conditions

Seas are usually rough during active prefrontal weather owing to a combination of strong surface winds and storm-generated swell arriving from the west. Since prefrontal southeasterlies reach their peak strength near frontal passage, prefrontal sea conditions may be expected to be roughest at that time. However, because of fetch and duration limitations, maximum waves will be no more than 8 feet high.

Effects on Range Operations

Range operations are severely hampered during active prefrontal weather. In 85% of the cases, IFR (instrument flight rules) conditions are observed because of low ceilings and poor visibilities. These conditions occur on the average from about 5 hours before frontal passage to just after frontal passage, when ceilings normally rise, visibilities improve, and precipitation usually ceases (figure 8-16). Additional potential hazards to aircraft occur from the turbulence caused by the strong southeast winds, and also sometimes from icing conditions at the lower freezing levels. At sea, high waves, blowing spray, and poor visibility markedly restrict operations over water.

Temperature

Temperatures during prefrontal conditions are best described by comparing them with normals for the time of day. During the day, clouds and rain result in temperatures cooler than normal because incoming solar radiation is effectively shielded from the ground. At night, however, the same blanket of clouds prevents that heat existing from the overwater trajectory of air from escaping to space. Nighttime minimums, even in winter, may hover near 60°, far above normal for the time of day.

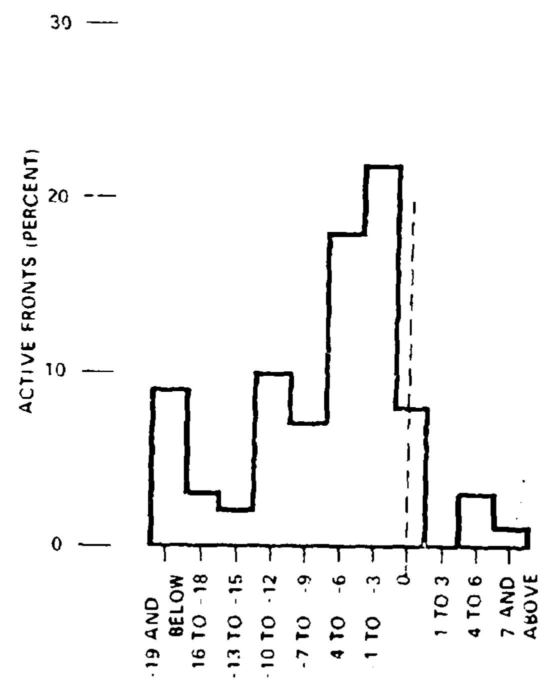
Dramatic temperature changes rarely if ever accompany frontal passages at Point Mugu. During especially active frontal passages, a drop in temperature and dewpoint of 1° or 2° is typical (temperature increases may be observed with the passage of dry fronts, particularly those from the east).

Pressure

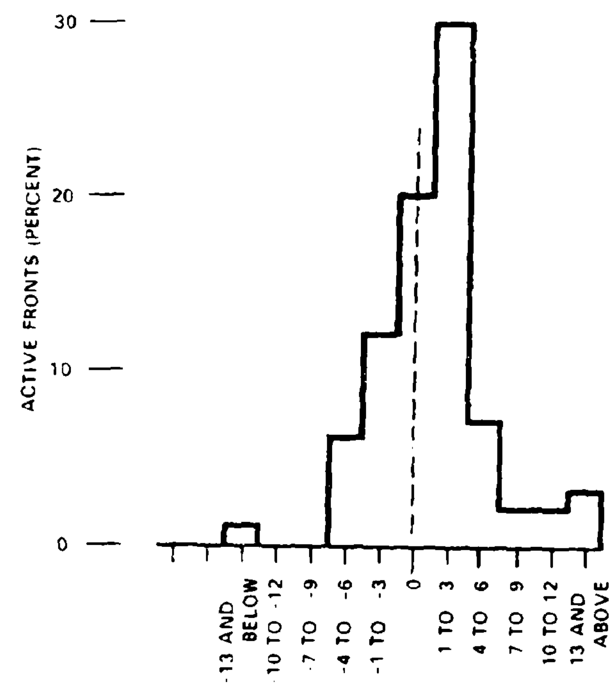
Pressures usually show a small steady drop during prefrontal weather. This drop may be masked by the semidiurnal pressure curve. Near frontal passage, the pressure drop may be more sharp and is followed by a corresponding sharp rise immediately following frontal passage. Station reports of "pressure falling rapidly" often indicate that the front is near.

FIGURE 8-16

NOTE 85 PERCENT OF ACTIVE FRONTS HAVE ASSOCIATED IFR CONDITIONS.



(a) Time of First IFR Observation Relative to Active Frontal Passage.



(b) Time of Last IFR Observation Relative to Active Frontal Passage

Figure 8-16. IFR Frontal Weather (Reference 38).

San Nicolas Island and Sea Test Range

With two minor exceptions, prefrontal conditions over the San Nicolas Island and Sea Test Range area are basically the same as those observed over Point Mugu: winds are probably a little weaker, more from a southerly rather than southeasterly direction, and rainfall is probably less intense. A relative lack of orographic effects accounts for these conditions.

POSTFRONTAL WEATHER

Under postfrontal conditions, surface weather maps will normally reveal Point Mugu to be within the strong onshore flow, where isobars are oriented west-northwest to east-southeast, as shown in figure 8-5(a). Sometimes a surface trough of low pressure will remain off the coast, but this feature usually occurs in more northerly latitudes. Satellite pictures will typically show the cold frontal cloud band to be east and south of Point Mugu, with the local area being under either clear or scattered cellular clouds, such as those depicted in figures 8-5(a) and (b). At upper levels, maps reveal a cold trough located nearly over the station with these upper winds predominantly westerly. Extrapolation of the features in figures 8-5(a) and (b) will show typical positions of the front and trough under postfrontal conditions.

Precipitation

Once the front has passed, continuous precipitation usually ends abruptly (figure 8-7). In 87% of active fronts studied, continuous rain ended within 3 hours of frontal passage. When the frontal slope is unusually gentle or when another disturbance follows closely behind, precipitation may continue after the front has gone by. If this should happen, it is normally of a showery nature and falls from large cumulus or cumulonimbus clouds that sometimes form in the unstable postfrontal air. Such showers may be heavy at times and are most pronounced when the cold trough or low aloft is located right over the station.

Occasionally, active fronts are followed closely by another active front. A study of past data shows that only 1 out of 10 such fronts are followed by another within 4 days. Active fronts followed by Santa Anas are more frequent. From the same study, (reference 38) it was found that this occurs with 1 out of 4 so-called wet fronts, and it generally takes 2 $\frac{1}{2}$ days for the Santa Ana to begin.

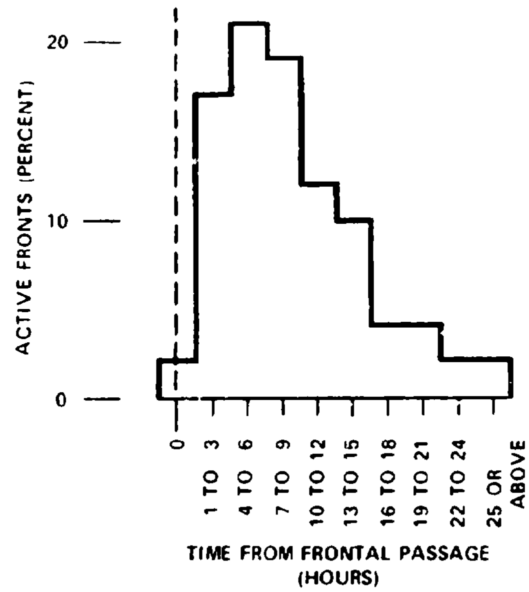
Sky Conditions

Following active frontal passage, clouds are higher than before frontal passage. This is due to

the drier air advected in behind the front. Typical heights of postfrontal clouds are about 1,900 feet. The most frequent cloud type is stratocumulus or cumulus, again indicative of the instability commonly observed behind the front. Normally, postfrontal clouds do not cause a complete ceiling for very long after frontal passage. Three out of four active fronts are followed by clearing (clear or scattered conditions) within 12 hours of the passage of the front (figure 8-17). In only 5% of cases studied have clouds persisted from frontal passage to the next disturbance without breaking up. When conditions are especially unstable, cumulonimbus clouds and thunderstorms may be scattered over the area. They appear to occur most frequently over the warmer water during the night, occasionally drifting over land to produce heavy showers over Point Mugu. Generally, however, under postfrontal conditions, cumulus clouds over land are larger than those over water due to orographic lifting.

Visibility

Because of the absence of fog, precipitation, and small aerosols in the cooler, drier, and unpolluted air mass, postfrontal visibility is normally much better than prefrontal visibility. Whereas prefrontal visibilities may lower to less than 1 mile, postfrontal visibilities typically average about 14 miles, and in many cases over 20 miles. Only occasionally are visibilities low, and then mainly due to rain in postfrontal showers. The best visibilities usually occur



NOTE

1. SEVENTY-TWO PERCENT (APPROXIMATELY THREE OUT OF FOUR) OF ACTIVE FRONTS ARE FOLLOWED BY CLEARING (SCATTERED SKY CONDITIONS) WITHIN 12 HOURS AFTER FRONTAL PASSAGE.
2. EIGHTY-SIX PERCENT OF ACTIVE FRONTS ARE FOLLOWED BY CLEARING (SCATTERED SKY CONDITIONS) WITHIN 18 HOURS AFTER FRONTAL PASSAGE.
3. FIVE PERCENT OF ACTIVE FRONTS ARE NOT FOLLOWED BY CLEARING (SCATTERED SKY CONDITIONS) BEFORE THE NEXT DISTURBANCE OR CLOUDY PERIOD.

Figure 8-17. Time of Postfrontal Clearing Relative to Active Frontal Passage (Reference 38).

the first day after frontal passage. It is on such days that the previous day's precipitation may be seen as snow cover atop distant mountains.

Winds and Turbulence

Following passage of the front, winds usually become westerly or southwesterly, but rarely northwesterly. These winds are characteristically strong, but not so strong, however, as prefrontal winds. When frontal passage takes place early in the day, afternoon westerlies may be particularly strong because of the addition of a strong sea breeze component. Even at night, when winds are normally light, postfrontal westerlies may be sufficient to warrant the issuance of wind warnings. On the average, postfrontal winds are about 10 knots, but winds of gale force are occasionally observed after a brisk active frontal passage. Light to moderate turbulence in the lower layers is associated with these brisk postfrontal winds. In fact, with skies relatively clear, high winds and turbulence remain as the only major hindrance to flying operations.

Freezing Level

Following frontal passage, the freezing level over the local area continues to lower as the cold air aloft is advected into the area. If postfrontal showers are occurring over the mountains, precipitation may fall there as snow. NOTE: Snow cover can nearly always be distinguished from clouds on satellite pictures because snow tends to remain day after day in the same place and often exhibits a dendritic pattern over mountains, as shown in figure 8-18 of the Canadian Rockies and Coast Ranges of British Columbia.

Figure 8-18. Snow Cover on Mountains Shown by Satellite, 1929Z, 10 May 1968.

Sea Conditions

As with active prefrontal weather, postfrontal sea conditions are usually rough. The combination of strong westerly winds, heavy westerly swell, and

a high tide may well result in inundation of beach-area instrumentation sites. Waves over the open water frequently are too high for safe travel of small boats.

Effects on Range Operations

Owing to the prevalence of clear or partly cloudy skies and good visibility, postfrontal weather is usually good for conducting range operations. However, strong winds and turbulence may well limit flying in lower layers of the atmosphere or launching small rockets. Occasionally, postfrontal showers will temporarily lower field conditions to below minimums, but such occurrences are almost completely confined to the few hours immediately after frontal passage. Over the Sea Test Range, rough seas may be an important factor.

Temperature

In the daytime, postfrontal temperatures are usually warmer than prefrontal ones because of more sunshine, but are decidedly cooler than prefrontal temperatures at night, since clear skies permit radiation of heat to space.

Pressure

Atmospheric pressure normally rises following frontal passage, but when a pronounced surface trough remains offshore, such rises are negligible and may even be masked by the downward cycle in the diurnal pressure curve. Even when unmasked by other phenomena, pressure fluctuations associated with frontal passages at Point Mugu are not nearly so regular and noticeable as those associated with fronts at typical inland mid-latitude stations and are therefore seldom reliable as forecast aids or frontal indicators.

San Nicolas Island and Sea Test Range

San Nicolas Island and the Sea Test Range are particularly vulnerable to strong west-northwest winds that follow an active frontal passage. Frequently, winds reach gale force. Over the water, wind-whipped waves create very rough seas, which, like the wind, may persist for a few days. If seas are especially rough, sea clutter may cause difficulties in tracking and guidance of targets and missiles by radar and radio signals. In other respects, such as cloudiness and visibility, postfrontal conditions are very much like those experienced at Point Mugu.

FORECASTING ACTIVE FRONTS

Causes

Analogous to the description of the causes of dry fronts, active fronts can be thought of as the leading edge of unmodified surges of fresh polar air that accompany relatively strong cold troughs aloft. These troughs characteristically have sufficient

southerly flow and upward motions preceding them to result in extensive frontal precipitation and cloudiness. Unlike the situation with a dry front, the unstable atmosphere accompanying these systems usually precludes any low-level inversions or well-defined marine layer, so that changes in frontal weather and air mass occur right down to the surface. A region of strong PVA (positive vorticity advection) usually overlies the surface frontal position.

Frequency of Passage

Although the number of active fronts passing through the Point Mugu area varies considerably from year to year, the average is about 5 per year. In addition to these, there are about another 10 rain-producing systems that, while mostly frontal in origin, lack the clear-cut wind shifts and other characteristics at the time of their passage through southern California to permit their being defined as active fronts in the sense that it has been used so far.

Preferred Paths

Figure 7-4 showed the wintertime preferred paths of dry fronts, but the same northwest to southeast swath down the coast indicated as the major path of dry fronts is equally representative of the movement of active fronts through Point Mugu and southern California. A few additional active fronts approach Point Mugu from the west, but no active fronts in the sense used here have been observed to approach the Station from the northeast.

Speed of Movement

Most active fronts are embedded in a stream of strong westerlies (even though north-south components may be large) and are relatively fast-moving, with forward speeds ranging from about 15 knots to as high as 40, with the typical speed averaging near 20. Unlike dry fronts, active fronts are usually well defined and easily determined from standard or routine meteorological measurements; thus there is little difficulty in placing them correctly on surface weather maps, particularly since excellent satellite picture coverage over the northeast Pacific is now available.

These satellite pictures, together with extrapolated frontal band positions based on surface hourly reports provide good estimates of the forward speed. Because of the higher topography north and east of Point Conception, rain-producing fronts slow down or "hang up" upon reaching that area; however, the slowing down seems to apply more to the dissipating, already slow-moving fronts than to the really active fast-moving ones.

Use of Vorticity and Satellite Pictures

Vorticity troughs deeper than those noted for dry fronts are usually associated with active fronts. Of more significance is a region of strong vorticity

gradient (tight packing of vorticity isopleths) both ahead of and behind the vorticity trough. The one ahead of the trough is a region of strong PVA and strongest upward motions. It is also the location of the active front and associated heavy cloudiness, strong winds, and rain. They are related not by coincidence but by dynamic cause and effect relationships. In the absence of ship reports and satellite coverage over the Pacific on any given day, the present and future positions of an advancing active front may be well estimated by choosing the location of the present and forecast positions of the pretrough region of strong vorticity gradient. Frontal weather (winds, clouds, and rain) should begin when the tight gradient first reaches the local area, and frontal weather should end (frontal passage) when the tight vorticity gradient passes the local area even though the vorticity maximum itself may still lie to the west. Figure 8-19 shows part of a vorticity analysis and 12-hour prog made at 1200Z on 30 November 1967. The active front associated with this system actually passed the Station at about 0730 PST. In this case, the 12-hour prog of vorticity was a little slow in that it did not show the vorticity gradient far enough eastward as shown by analyses made 12 hours later. It does illustrate, however, the progression of the regions of strong vorticity gradient and PVA. This rather subjective but noticeable feature should be used more by local forecasters in predicting rain, and much less attention should be paid to the actual value of vorticity. Although very high values do imply strong cyclonic centers, they do not by themselves necessarily imply heavy clouds and rain, since moisture content of the air is an important factor. To emphasize the point, some of Point Mugu's heaviest rainfalls have occurred with very low values of vorticity (3 or 4) but within a region of strong vorticity gradient and moist flow. Appendix A contains a more detailed description of the meaning and use of the term vorticity.

When satellite pictures are available, they should be regarded as the best tool for determining both frontal positions and intensity and also the trend of these over a period of several hours or days. Therefore, maximum use should be made of satellite pictures by the forecaster. The example shown in figure 8-1 shows how well-defined and clearly visible the various cloud features and structures of active fronts can be.

Active fronts are not the only features that are easily distinguishable on satellite pictures. Virtually all atmospheric features that have been discussed or will be in the following sections are associated with characteristic cloud patterns or voids. This includes cold lows, troughs, regions of offshore flow, jet stream cirrus, and tropical storms on the synoptic scale as well as eddies, individual thunderstorms, and variations in stratus cover on the meso-scale. The forecaster will greatly benefit from familiarizing himself with the way these characteristic cloud patterns appear on satellite pictures, and three of the best references available for use have been published

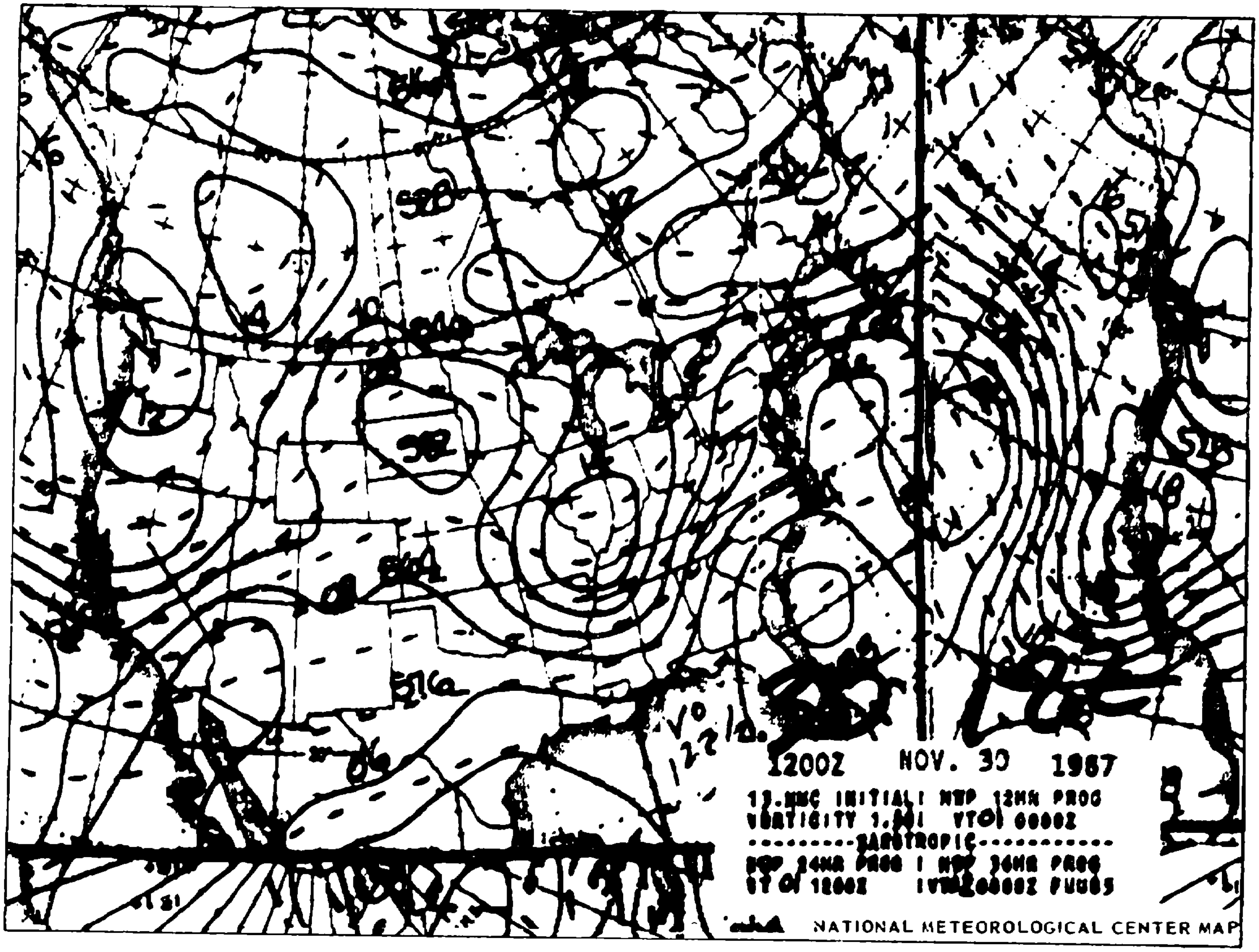


Figure 8-19. Barotropic Vorticity Analysis and Prognosis of 1200Z, 30 November 1969.

by the Navy Weather Research Facility (now the Navy's Environmental Prediction Research Facility) and Project FAMOS (Fleet Applications of Meteorological Observational Satellites): Oliver and Bittner's The Use of Satellite Pictures For Surface and 500-mb Chart Analyses (reference 50), Bittner's Guide for Interpretation of Satellite Photography and Nephanalyses (reference 51), and the more recent one by Bittner and CDR Ruggles entitled, Guide for Observing the Environment With Satellite Infrared Imagery (reference 52). The latter deals with the newer infrared pictures, which differ from the conventional visual imagery in that radiated heat rather than reflected light is detected by the satellite. This means that infrared pictures show not only the location of cloud patterns but also provide information on their temperature, which in turn permits estimates to be made of cloud type, altitude, and density. Thus, infrared pictures can separate mid-clouds from the higher, colder (and on infrared pictures, much whiter) cirrus clouds which conventional visual photographs can not.

Most of the satellites planned for the future will be operating with infrared scanners, so that both infrared and conventional visual pictures will be available to the forecaster. The use of both types of pictures together, when used with available surface and upper air analyses, will greatly enhance the forecaster's ability to describe the present state of the atmosphere over the Northeast Pacific and the West Coast.

Other Weather Signs and Aids

Several other aids and sources of information are available to the forecaster to help in determining whether a specific front will affect Point Mugu and how much weather and rain may be expected.

First, the seasonal or "climatological" factor must be considered. An active front in April is less likely to produce heavy rains at Point Mugu than one in February. As the northern hemisphere heats up in spring, active fronts weaken rapidly as they move southward, and there is a greater likelihood that they will ride up and over a dense surface-based marine layer. In the fall, a combination of several seasonal and synoptic factors appears to cause an anomalously frequent and heavy period of precipitation during the middle 10 days of November (reference 42). This rainy climatological period may or may not be frontal in nature and will be discussed briefly under "Other Cyclonic and Rain-Producing Circulations That Affect Point Mugu," chapter 9.

Second, several large-scale or synoptic factors must be considered. The 850-mb maps should be inspected to determine if a moist tongue is present in the warm air leading into the frontal zone. If so, more rain can be expected at Point Mugu than in the average case. These situations will generally be reflected on satellite pictures, which should show considerable cloudiness ahead of as well as within the frontal band. The width of the frontal band is a

very important feature: wide ones (200 miles or more) indicate a longer duration of precipitation and strong winds with due consideration for the speed of movement of the front. Exceptionally bright areas seen on visual and infrared satellite pictures within the frontal band may be properly interpreted as dense convective cells under which heavy rain and possible thunderstorms are occurring.

Sometimes a secondary region of cloudiness will appear to the rear of the front. This is often associated with vorticity maxima (and associated strong vorticity gradients) moving rapidly through the cold air and is generally comma-shaped (reference 50). These cloudy regions are important because they may presage formation of a new frontal zone and generally produce a new rainy period shortly after passage of the original front. Such a second rainy period should not be attributed to the passage of the trough aloft or upper low, which is actually often cloud-free or only partially cloud-covered, particularly for cutoff lows (reference 50).

A very important rule based on observation from satellite pictures and also on theory is that fronts are active and rain-producing north of the point where the 500-mb trough line intersects the surface front. In other words, north of the intersection, the front precedes the trough aloft, and all the active weather occurs there. South of the intersection, the surface front lags the trough aloft, and the front shows marked weakening with breaks in the frontal clouds and a general lack of active weather. Forecasters should consider the speed of movement of both the front and trough aloft to determine if this intersection of the two will occur north or south of Point Mugu. It may make the difference between heavy rain and no rain at all. Somewhat related is another rule that states that along the West Coast no rain will fall from any frontal system south of the highest surface pressure measured along the coast. Thus according to this rule, the forecaster should inspect the surface analysis and find the spot along the coast where the pressure is reported to be highest. If that point lies north of Point Mugu and is expected to remain that way, the chances of rain falling at the Station are very small. In an analogous criteria for upper air features, the Los Angeles office of the National Weather Service uses the 5640-meter contour ("564") of the 500-mb level to mark the southern edge of a storm area likely to experience rain (this does not apply to warm rains, such as those that occurred during January 1969). This and the other previously mentioned aids and observations are among the many ingredients that the National Weather Service feeds and assimilates into its regional guidance forecasts and issues in the FPUS Summaries that are received over teletype four times daily at about 2 and 8 o'clock local time. They provide a simply worded (abbreviated) forecast of conditions over southern California and the reasoning followed in arriving at those forecasts. Rainfall probabilities for several stations within the regional area are provided at the end of the summary. A sample of one with indicated explanations as needed

is provided in figure 8-20. This is one further tool available to the local forecaster that is a valuable asset when used with the other aids.

Third on the list of major considerations are the relatively local or mesoscale influences on frontal weather over Point Mugu. The coastal mountains generally cause extra lifting of moist air, which produces heavy clouds and rain along the coast and slopes of hills far exceeding the amounts generally received from the overall synoptic disturbance. If the prefrontal pressure gradient is sufficient to produce strong southeast winds, some of this enhanced rainfall will occur at the Station, although the rain shadow effect discussed under "Precipitation" in the section on Prefrontal Weather will prevent the amounts from being as much as coastal slopes would experience.

When sea surface temperatures are high, as they characteristically are during the fall months, more moisture will be added to the lower levels of the atmosphere and instability will be large enough to convert that extra moisture into clouds and rain.

The clouds themselves may provide a simple subjective clue to the weather to follow. Large cumuliform buildups over the water are generally a sign of large-scale rising motion such as that which precedes active fronts; typically, such clouds are followed by rain at the Station. When the buildups over land become larger than those over water, it is

DAY
TIME(Z)

```
LAX
ZCZC
 FPUS3 KLAX 230959
UPR RDG INDCD TO MOVE EWD AND FLATTEN AND S/W
FNTL TROF IN PAC TO MOVE EWD INTO DIST ERY SAT.
BACLIN PROGS SHOW THIS TROF MUCH DPR IN DIST
THAN BATROP PROGS. PREFER BACLIN PROGS BUT W UPR
TROF NOT QUITE SO DP AND WX FNT NOT EXPCD TO
MOVE INTO DIST UNTIL ABT MIDDAY OR LATE SAT.
SOME RAFL LKLY W S/W TROF NRN CSTL AND MTN AREAS
BY LATE FRI NGT. CHC OF RAFL SPRDG SWD THRU ALL
CSTL AND MTN AREAS SAT AND BCMG MDT AT TIME N
PTN. WDSPRD CSTL FOG AND LOW CLDS LFTG W DPNG
MARINE LYR AND DRZLS BY FRI NGT. LCTMPS. OTLK
SUN FAIR TO PTLY CLDY W S/W RDG MOVG INTO DIST.
LAX +13 BIH Ø25 LAS Ø+- SAN +-2. ERNST.
```

FIRST 12-HOUR PERIOD
SECOND 12-HOUR PERIOD
THIRD 12-HOUR PERIOD
0%
20%
50%
STATION (SAN DIEGO)
2%
5%
20%
NAME OF FORECASTER

Figure 8-20. Example of FPUS Summary Forecast From Los Angeles (LAX) for 23 January 1970.

generally an indication that the front and greatest instability have already passed Point Mugu and no more rain should be expected locally. West coast studies (references 53 and 54) have shown that even the region of large vertical motions and heavy clouds ahead of the front is composed of bands of heavier convective elements superimposed on an otherwise nearly uniform frontal cloud sheet, so that oscillations in rainfall intensity should be expected by the forecaster before the heaviest rain and frontal passage occur.

Finally, there are a few objective techniques developed at Point Mugu that may be applied to the forecasting of rain and its implied frontal weather. One that is being used operationally (reference 55) is based partly upon techniques developed by the Naval Postgraduate School (reference 56) and the Weather Bureau (reference 57). The PMR method compares certain con[illegible]r input parameters (listed in table 8-1) and assigns weighting factors to them in relation to their assumed influence on local rainfall. In effect, the human forecaster does the same thing when he looks at a weather map and considers local pressure, positions of highs and lows, vorticity and its advection, upper air patterns, satellite cloud pictures, and time of year. The human memory, however, is not normally capable of remembering the exact effect each parameter had on local rainfall in the past several years. The computer program, on the other hand, has an objective but simplified and limited climat[illegible]gy built into it.

Table 8-1. Parameters Used in PMR Objective Forecast of Rainfall Probability

First 12 Hours
Month
500-mb height, northeast Nevada, initial
Vorticity, Point Mugu, initial
Vorticity, Point Mugu, first 12-hour change
500-mb height, Point Mugu, initial
500-mb height, Point Mugu, first 12-hour change
500-mb height, Point Mugu, third 12-hour change
Surface pressure, Point Mugu
Surface pressure, Point Mugu, minus surface pressure San Francisco
Surface pressure, Point Mugu, minus surface pressure Las Vegas
Second 12 Hours
Month
Vorticity, Point Mugu, first 12-hour change
Vorticity, Point Mugu, second 12-hour change
500-mb height, Point Mugu, second 12-hour change
Surface pressure, Point Mugu
Surface pressure, Point Mugu, minus surface pressure, San Francisco
Third 12 Hours
Month
500-mb height northeast Nevada
Vorticity, Point Mugu, second 12-hour change
Vorticity, Point Mugu, third 12-hour change
500-mb height, Point Mugu, second 12-hour change
500-mb height, Point Mugu, third 12-hour change
Surface pressure, Point Mugu
Surface pressure, Point Mugu, minus surface pressure, San Francisco

Notes: There have been some changes from the original concept in some of the parameters:

1. The latest computations consider successive 12-hour changes rather than 12-, 24-, and 36-hour changes from the original values.

2. The surface-pressure difference between Point Mugu and San Francisco rather than Eureka is used, since it was found that deep lows that lower the pressure drastically at Eureka occasionally did not affect Point Mugu.

3. An independently derived factor that considers the 500-mb gradient is combined with the computed factor to produce a modified factor.

Forecasts are made for each of three consecutive 12-hour forecast periods. A sample printout of a forecast for 23-24 January 1970 is presented in table 8-2. Included are rainfall "probabilities" for various amounts of rain and an estimated maximum east-west surface wind component.

Verification and comparison of the objective technique with subjective forecasts is difficult. One problem is that subjective and objective forecasts are not strictly comparable, since the former is categorical (explicitly gives a "yes" or "no" answer) and the latter is probabilistic (gives the likelihood of various amounts of rain in percentages). In addition, there are differences in the time of day at which each is normally and operationally prepared.

In general, subjective forecasts have the advantage of incorporating such things as hemispheric and synoptic scale history and trends, local topographic effects, latest hourly reports, and forecasters' intuition, etc. Objective forecasts enjoy the distinct advantage of explicitly incorporating detailed climatological hindsight and provide a routine operational tool to the forecaster that was not available to him before. Refinements in the program's use of vorticity trend information will further improve the usefulness and reliability of the program to the forecaster.

Another statistical study under development at PMR is the Mesoscale Weather Correlation Study. Atmospheric Sciences Technical Note No. 25 (reference 40) contains numerous graphs and diagrams that permit objective forecasts of wind conditions at Point Mugu as a function of winds near 3,000-feet altitude at Vandenberg AFB, and some of these apply directly to frontal weather conditions. Figure 8-21, extracted from the report shows, for instance, that Point Mugu can expect moderate southeasterlies nearly all day (prefrontal southeasterlies) when Vandenberg's 1-kilometer winds are strong ($\geq$9 meters per second or $\geq$24 knots) from the south-southwest (210°). A slight shift to south or south-southwest is evident for Point Mugu's winds in late afternoon, which is frequently observed during frontal conditions. When Vandenberg's 1-kilometer winds are strong, but from the west-southwest (240°)--a typical postfrontal wind--Point Mugu experiences strong west-southwest winds nearly all day at the surface. These winds are also typical for Point Mugu following frontal passage. Other usable correlations are obtainable from this progress report for use by the forecaster.

In addition to PMR's efforts, other National Weather Service and private efforts are being made along the West Coast to quantify forecasts of rain and frontal conditions in California. One of these (reference 58) relates vertical motions and jet stream positions and thickness to occurrence of various amounts of rainfall and derives a "synoptic climatology." These are available to local forecasters for inspection and study.

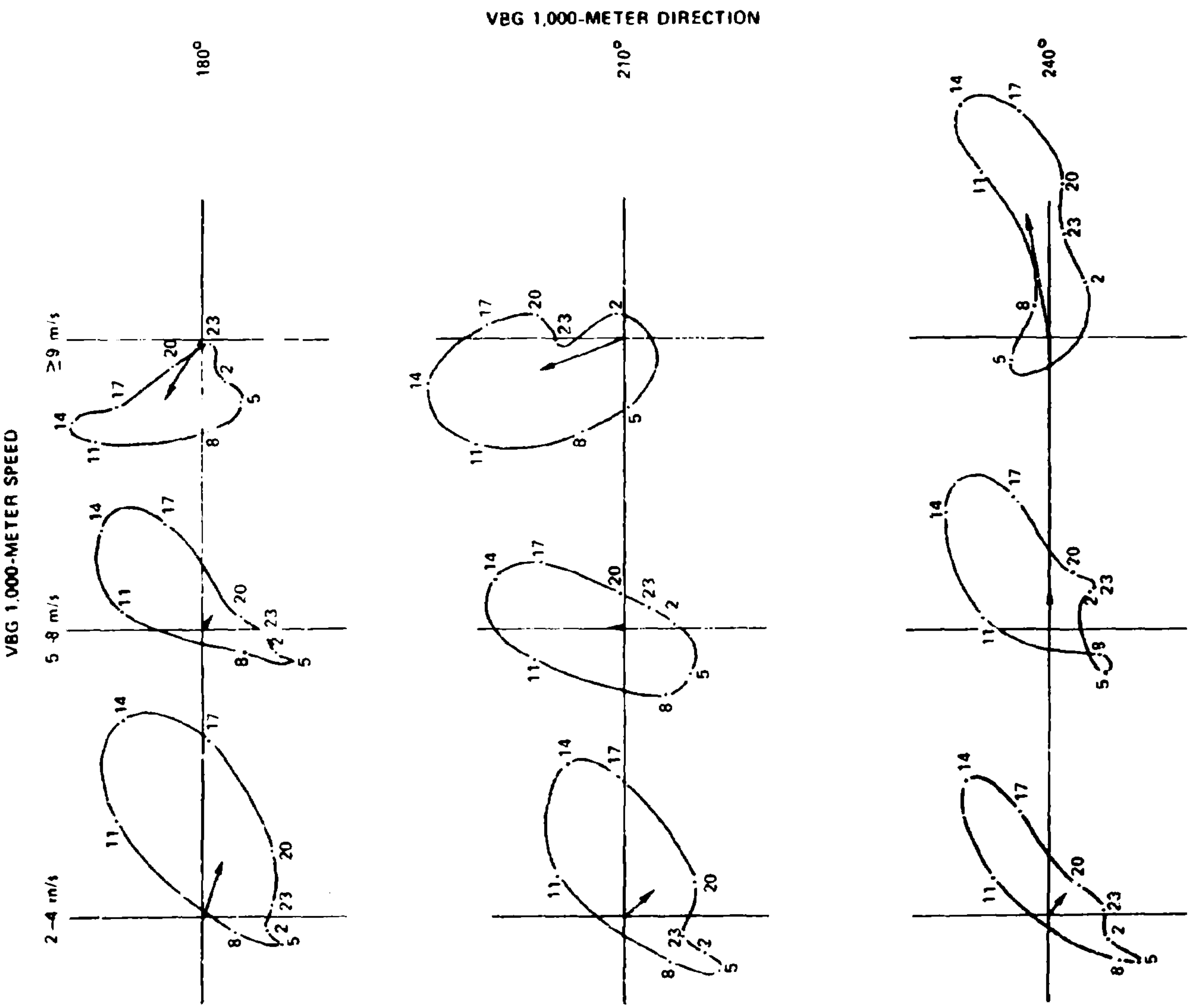
Table 8-2. Computer-Processed Objective Forecast for 23-24 January 1970

```
FIRST 12 HOURS FROM 2312
                                                  MAX EST WIND 8KNOTS WEST COMP
FACTOR          .03710        AFACTOR        .01979
PROBABILITY OF ANY RAIN        4 %
PROBABILITY OF GT .05 INCHES   2 %
PROBABILITY OF .1 INCHES       0 %    (Forecast for 23 Jan.'70 0400-1557 PST)
PROBABILITY OF .3 INCHES       0 %
PROBABILITY OF .5 INCHES       0 %
PROBABILITY OF .7 INCHES       0 %
PROBABILITY OF .9 INCHES       0%

SECOND 12 HOURS FROM 2312
                                                  MAX EST WIND 0KNOTS EAST COMP
FACTOR          .07683        AFACTOR        .07723
PROBABILITY OF ANY RAIN       21 %
PROBABILITY OF GT .05 INCHES 13 %
PROBABILITY OF .1 INCHES       9 %    (Forecast for 23 24 Jan.'70 1600-0357 PST)
PROBABILITY OF .3 INCHES       2%
PROBABILITY OF .5 INCHES       0 %
PROBABILITY OF .7 INCHES       0 %
PROBABILITY OF .9 INCHES       0 %

THIRD 12 HOURS FROM 2312
                                                  MAX EST WIND 15KNOTS WEST COMP
FACTOR          .07989        AFACTOR        .08464
PROBABILITY OF ANY RAIN       24 %
PROBABILITY OF GT .05 INCHES 15 %
PROBABILITY OF .1 INCHES      10 %    (Forecast for 24 Jan.'70 0400-1557 PST)
PROBABILITY OF .3 INCHES       3 %
PROBABILITY OF .5 INCHES       0 %
PROBABILITY OF .7 INCHES       0 %
PROBABILITY OF .9 INCHES       0 %
```

FIGURE 8-21



NOTE: 3-hourly mean vector winds blow from origin *toward* points on curves, labeled with center hour (PST) of time category.
Axes of individual diagrams are 5 knots in length from origin to end.
Direction categories are 30 degrees wide, center direction indicated.
Daily resultant mean vector winds shown by short arrows.

Figure 8-21. Diurnal Mean Vector Surface Wind at Point Mugu as a Function of Reference Wind Direction and Speed, All Seasons, 1949 – 1964. (From reference 40.)

THUMB RULES AND FORECASTING AIDS ON ACTIVE FRONTS

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
The great majority of fronts passing Point Mugu are dry.	✓			7-3*
Fast-moving fronts usually do not slow down appreciably before reaching Point Mugu.		✓		8-31
Slow-moving fronts often "hang up" or dissipate in the mountains north of Point Mugu.		✓		8-31
Strong winds are associated with active fronts.	✓			8-22,-29
The approach of fronts causes the inversion to rise.	✓			7-3*
Much of Point Mugu's annual rainfall occurs from November to April from [illegible] and fronts from the Pacific.	✓			7-11*
Frequency				
Active frontal passages average only 5 per year at Point Mugu but there are at [illegible] other front-related rains.	✓			8-31
Active frontal passages appear to be more frequent in the afternoon and evening hours than in night and morning hours.			✓	**
Only 1 out of 10 active fronts are followed within 4 days by another active front.	✓			8-27
A Santa Ana follows about 1 of every 4 "wet" fronts.	✓			8-27
When Santa Anas follow active fronts, they do so after about [illegible] days.	✓			8-27
Precipitation				
There will be at least one report of moderate or heavy rain associated with 4 out of every 5 active fronts.	✓			8-18
Heaviest precipitation usually occurs at frontal passage.	✓			8-18,-21
Continuous frontal rain usually begins about 2 hours after onset of southeast winds and about 6 hours before frontal passage.	✓			8-18,-19
Continuous frontal rain usually ends at or shortly after frontal passage.	✓			8-18,-19
Large cumulus over water and smaller cumulus over land means approach of an active front and rain.			✓	8-17,-36
Sky Conditions				
Lowest prefrontal ceilings are typically about 900 feet.	✓			8-21
The lowest prefrontal ceiling most frequently occurs at the time of frontal passage.	✓			8-21,-22

*See Chapter 7.
**See reference 38 (considered quite speculative at present).

THUMB RULES AND FORECASTING AIDS ON ACTIVE FRONTS (Continued)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Post-frontal cloud heights average about 1,900 feet.	✓			8-28
Post frontal stratocumulus and cumulus are marked by sharp bases and good visibility beneath.	✓			8-28
Three out of four active fronts are followed by clearing within 12 hours following frontal passage.	✓			8-28
Only 1 out of 20 active fronts are not followed by clearing.	✓			8-28
A clear band of 50-100 miles in width often appears between the trailing edge of a stratus deck and the leading edge of the frontal band.			✓	8-17
Visibility				
Prefrontal visibilities of less than 3 miles are common.	✓			8-21
Lowest visibilities usually occur at or just prior to frontal passage.	✓			8-21
Prevailing post frontal visibilities average about 14 miles.	✓			8-28
IFR Conditions				
85% of active fronts have associated IFR weather at Point Mugu.	✓			8-25
The most frequent time of the first IFR observation is 1 to 3 hours before frontal passage with the typical time being nearer to 5 hours before frontal passage.	✓			8-25, -26
The last IFR observation occurs on the average (within one hour) after frontal passage.	✓			8-26
Winds				
Prefrontal winds at Point Mugu are usually southeast.	✓			8-22
Post-frontal winds at Point Mugu are usually westerly or southwesterly, almost never northwesterly.	✓			8-29
Prefrontal southeasterlies are stronger than post-frontal westerlies.	✓			8-24, 29
Both prefrontal and post-frontal winds are usually strong enouth to warrant the issuance of wind warnings.	✓			8-22, -29

THUMB RULES AND FORECASTING AIDS ON ACTIVE FRONTS (Concluded)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
The strongest winds are most frequently observed about an hour before frontal passage.	✓			8-22, 24
When VBG early morning 1-km winds are from SSW at moderate speeds, Point Mugu surface winds are SE nearly all day; when VBG winds are from WSW, Point Mugu winds are SW nearly all day.	✓			8-38
Weather Map Tips				
Active fronts coincide with a region of strong vorticity gradient (PVA).	✓			8-32
The actual value of vorticity locally means very little.		✓		8-32
No rain will occur south of the intersection of the surface front and 500-mb trough line.		✓		8-35
No rain will occur south of the highest surface pressure.		✓		8-35
No rain will occur south of the 5,640 meter contour of the 500-mb level.		✓		8-35
Satellite pictures are probably the single best tool the forecaster possesses.	✓			8-32, -34

CHAPTER 9. OTHER CYCLONIC AND RAIN-PRODUCING CIRCULATIONS THAT AFFECT POINT MUGU

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CHAPTER 9

WARM FRONTS

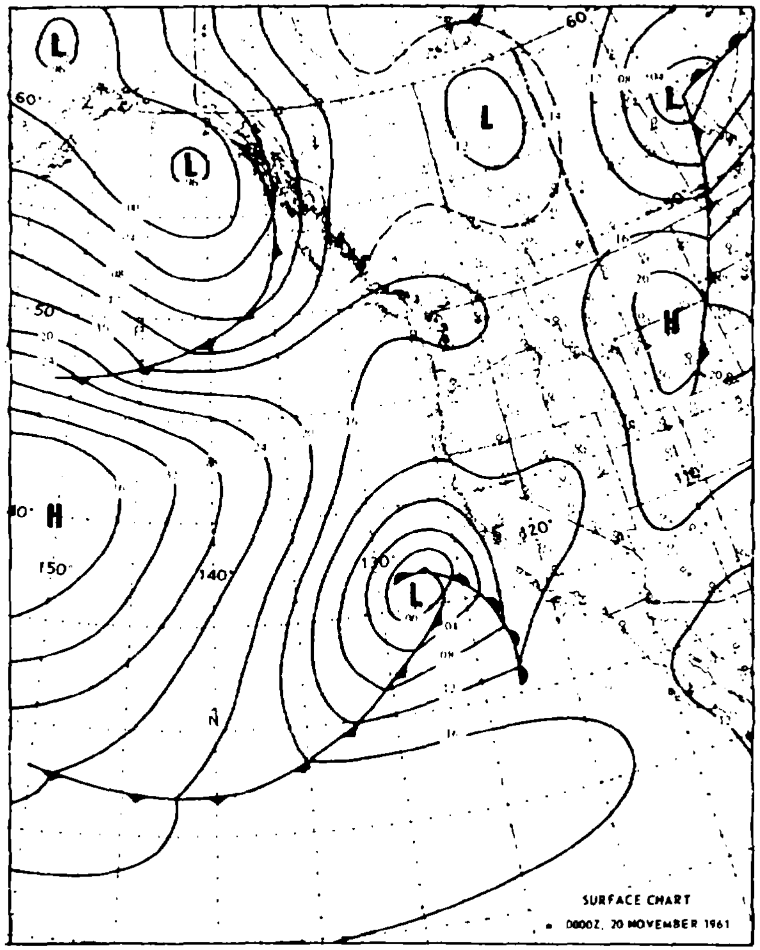
When a deep surface low is located south of 35° north, an infrequent situation sometimes develops in which passage of a discernible warm front occurs. The synoptic situation for such an occurrence is shown at the surface and at 500 mb in figure 9-1. In this example, large-scale overrunning of warm, moist air produced a classical stratiform cloud sheet which, after lowering, resulted in 0.62 inch of rainfall in a period of about 6 hours. The warm front then passed and was followed by brief typical warm sector weather with occasional light rain and fog, but came to an abrupt halt with the renewal of heavy rains as the cold front passed through the local area. The cold front rain produced another inch of rainfall in a period of only 2 hours.

Occurrences of warm frontal passages such as described in this example are probably limited to cases where the trough in the isotherms at 500 mb lags the trough in the height contours by several hundred miles so that a pronounced warm tongue of air immediately precedes the trough aloft. This feature and the accompanying warm advection can be seen in figure 9-1(b).

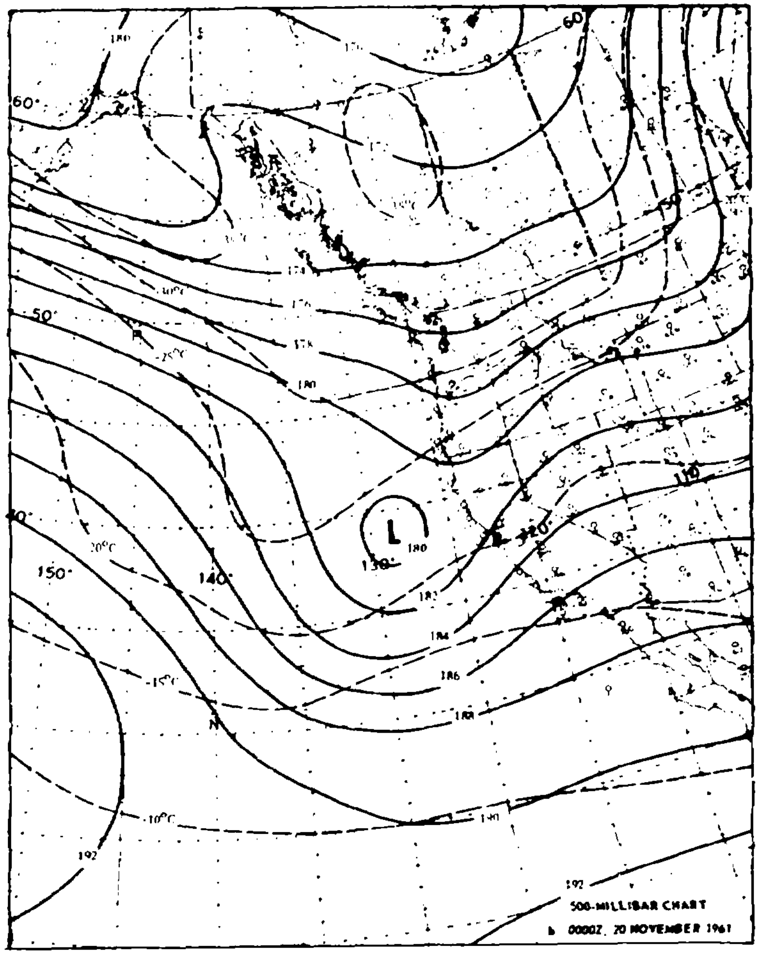
WARM RAINS OF TROPICAL ORIGIN -- THE CASE OF JANUARY 1969

Low-latitude disturbances far out in the Pacific may result in flows of warm, moist, and unstable air to the hilly coast of California resulting in very heavy, "warm," topographically-influenced rainfalls. There are usually no discernible frontal zones on National Meteorological Center analyses, and satellite pictures are often the only usable tool available to the forecaster in predicting clouds and rain. Noteworthy examples are the heavy rains of January and February 1969. The January rains resulted in a record 13.63 inches for that month at Point Mugu, and 9.63 inches of that fell from 18 to 26 January, nine consecutive days of rain. Much heavier rains occurred in mountain areas surrounding the Los Angeles Basin. On the 19th alone, Point Mugu reported 3.29 inches of rain. Attesting to the topographic nature of the precipitation is the fact that San Nicolas Island recorded only 0.14 inch for the same day. High dewpoints between 55° and 60°F (comparable to early summer readings) occurred on this day as well as on several of the other rainy days for this period, indicative of the tropical origin of the air. Warm drizzle falling from low stratus separated, and in some cases, occurred with the rainy periods.

FIGURE 9-1



(a) Surface Analysis of 0000Z, 20 November 1961.



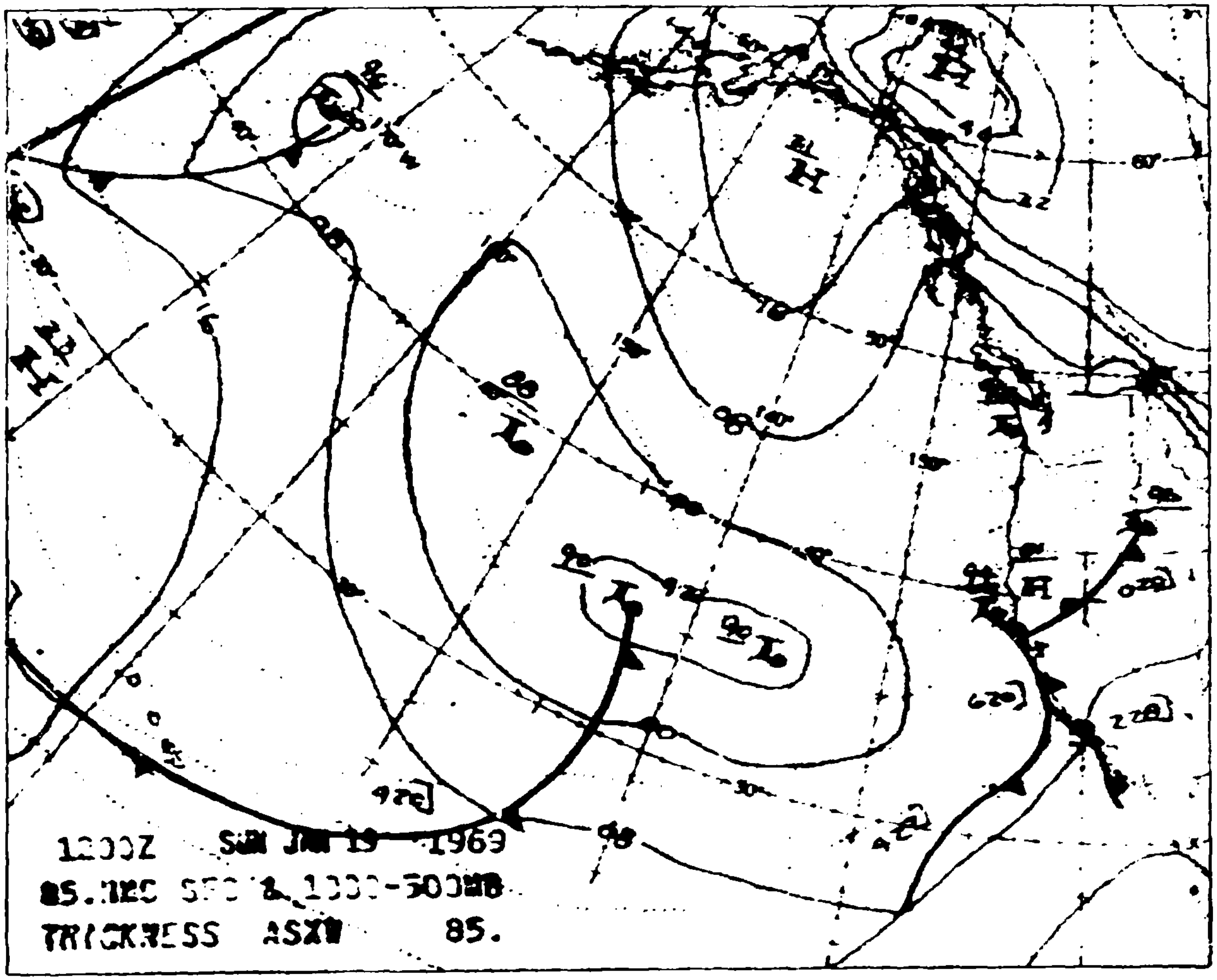
(b) 500-Millibar Analysis of 0000Z, 20 November 1961.

Figure 9-1. Typical Warm Front.

Figures 9-2(a) and (b) show the surface and 500-mb conditions for 1200Z on the 19th. At the surface, the persistent region of low pressure northeast of the Hawaiian chain is the most striking feature. A weak frontal system just off the California coast is analyzed; it extends well down into the tropics and would appear to be the direct and immediate cause of the heavy rains recorded at Point Mugu and throughout southern California. But there appears to be almost no thermal support for a frontal region at Point Mugu or at lower latitudes. The 500-mb analysis [figure 9-2(a) and (b)] shows a broad, flat west-southwest flow over California extending well to the west of Point Mugu. The wind flow, the relatively warm temperatures, and the lack of any pronounced features near the southern California coast hardly seem consistent with observations of continuous moderate and heavy rain. It certainly would not warrant the forecasting of continued heavy rains in the traditional sense of their occurring with sharp cold troughs moving through the area. The only source of information to lead forecasters to predict appreciable rain at the start of the period were satellite pictures which revealed very dense cloud masses stretching for hundreds of miles southwest into the tropics. As too often happens, forecasters throughout southern California put more reliance on the numerical National Meteorological Center prognostications (progs) and analyses than they did in the satellite (the real) picture of what was going on. An analysis of the January "storm" prepared at the University of California, Los Angeles (reference 59), revealed serious errors in analysis which led to erroneously stable conditions on successive National Meteorological Center progs. Had the intensity of the low-latitude disturbances near the Hawaiian chain been correctly ascertained, there would have been much higher vertical velocities (rising motions) forecast for southern California. But again, the best source of data -- the satellite -- went largely ignored, at least initially.

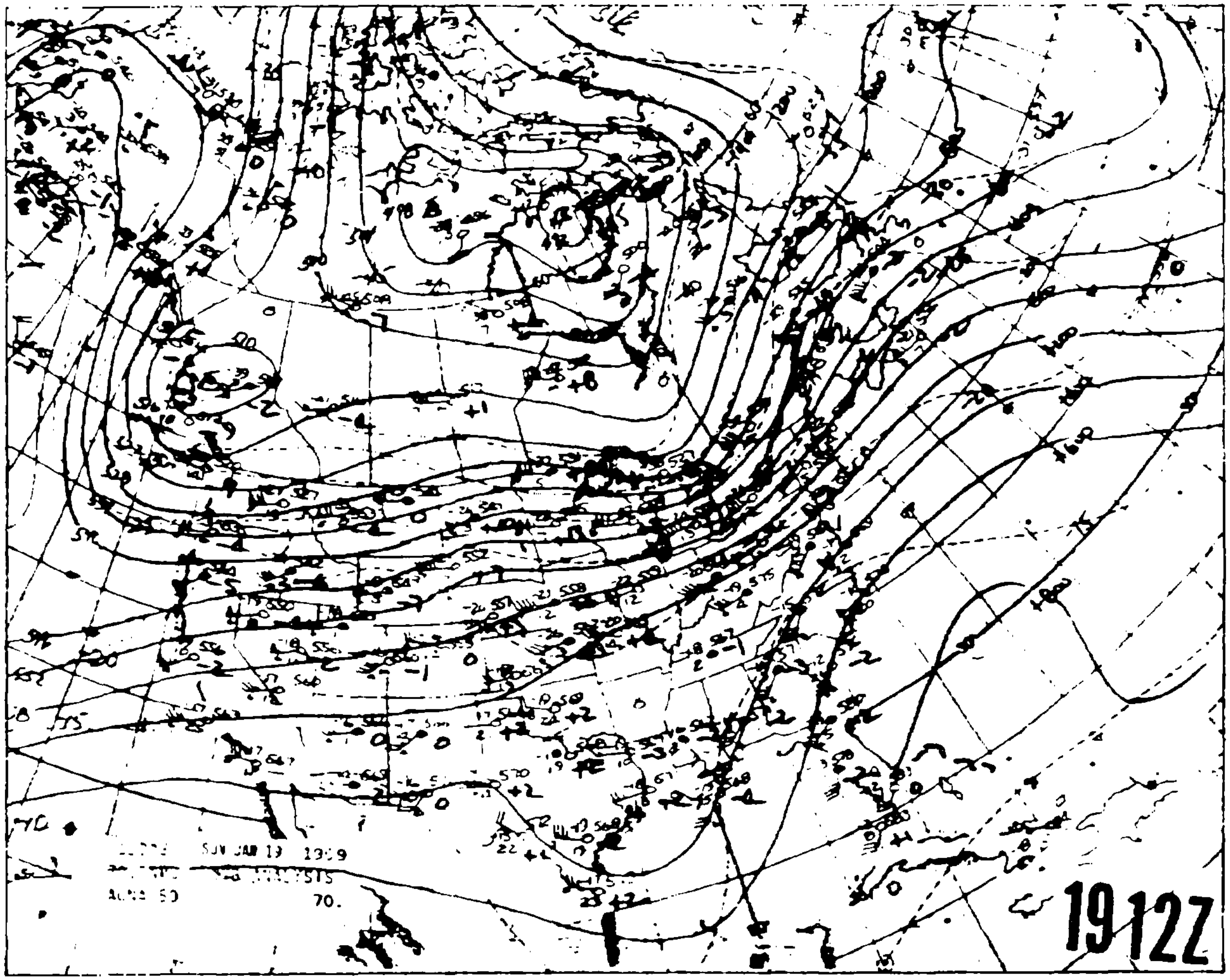
As for the mechanism which could ultimately be blamed for setting up the heavy, prolonged rain situation which resulted in up to 51 inches of rain in an 11-day period in some southern California mountain areas, a study by Namias (reference 60) traced the chain of events back to a warm pool of ocean water in the North Pacific which formed the previous spring. This, in turn, was formed by a sudden change in the atmospheric conditions such that the Hawaiian trade winds disappeared, and subsidence and clearing increased. The warm pool remained throughout the summer and fall so that disturbances traversing the area during the subsequent winter experienced more than normal intensification. The resulting low-pressure area near the Hawaiian region resulted in a series of weak impulses embedded in a vast flow of very moist, warm air which then caused the largely orographic rains in southern California. Such chain reactions due to air-ocean heat exchange appear to be common and may explain year-to-year fluctuations in weather (reference 61).

FIGURE 9-2



(a) Surface Analysis of 1200Z, 19 January 1969, National Meteorological Center Map.

Figure 9-2. Synoptic Maps During Heavy Rains of January 1969.



(b) 500-Millibar Analysis of 1200Z, 19 January 1969, National Meteorological Center Map.

Figure 9-2. Concluded

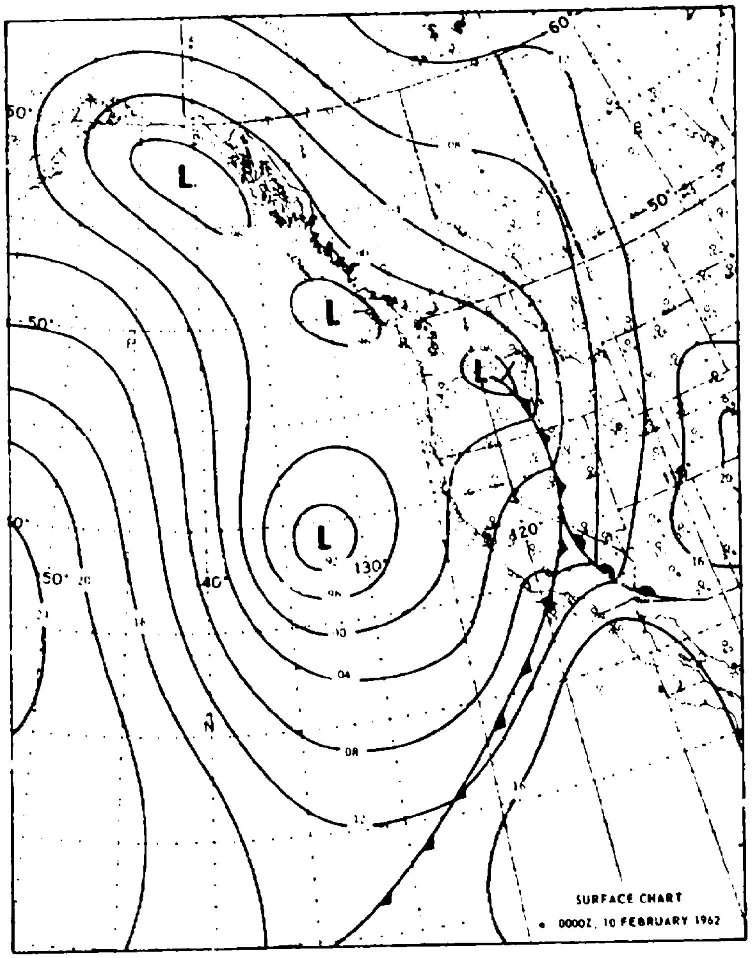
RAINY PERIODS DUE TO DEEPENING TROUGHS

Whenever a new surge of cold air enters upwind (west) of a trough in the westerlies, the trough undergoes deepening. A resulting tilt of the low pressure system with height toward the cold air results in the surface low and frontal activity being found under upper winds that have a strong southerly component and often a small eastward-steering component. Therefore, the surface low and frontal activity progresses only slightly to the east.

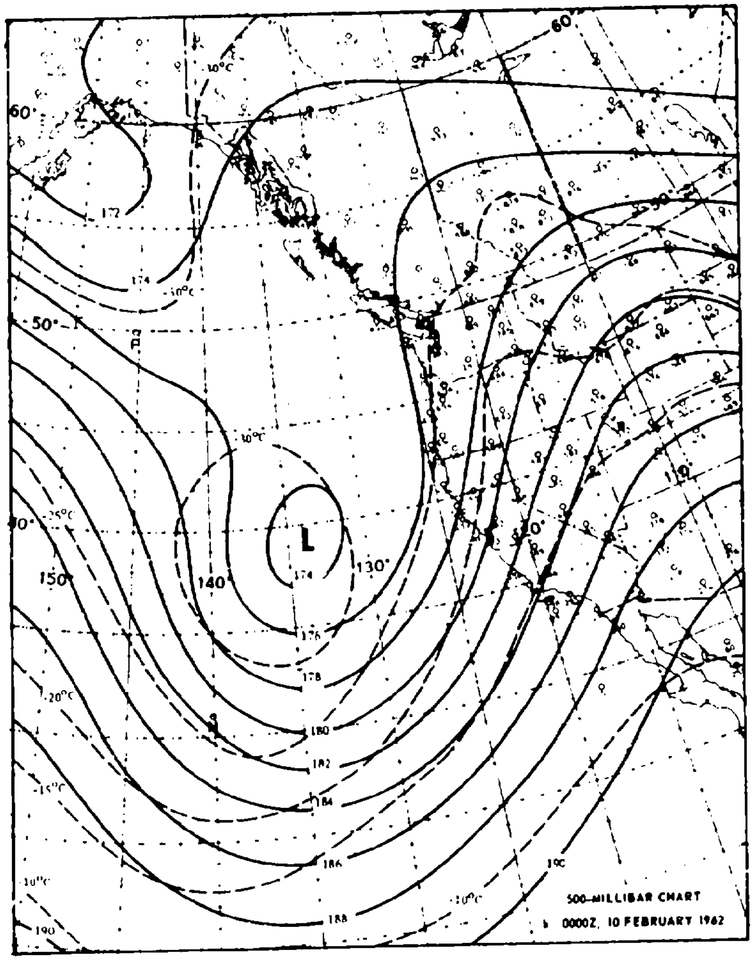
A deepening trough may be best recognized by the appearance of a pronounced dip in the isotherms to the rear of the trough. The resulting cold advection and intersection of isotherms and height contours causes vorticity to be generated. The greater the cold advection into the trough, the deeper the trough gets and the slower it becomes in terms of forward speed.

When such deepening occurs just off the California coast, a prolonged period of heavy rains may occur at Point Mugu. Figures 9-3(a) and (b) show the synoptic patterns for one of these rain periods in February 1962 which brought 10 inches of rain to Point Mugu in 4 days. The intensity and amounts recorded make this example analagous to the January 1969 deluge and probably also involved considerable amounts of tropical air brought up by the pretrough southerly flow. The low centers remained offshore during this rainy period as cold air streamed into the rear of the system. The result at Point Mugu was 1.17, 2.59, 2.76, and 3.52 inches of rain on February 7, 8, 9, and 10, respectively.

Deepening of the trough does not always result in heavy rain at Point Mugu. Sometimes a rain-producing trough will deepen and slow down just out of reach of the local area. The sudden deceleration of such a system presents a difficult problem to forecasters. Instead of the front and its associated weather moving into the local area, it will remain to the northwest and give central California an overabundance of rain while Point Mugu remains sunny, warm, and dry. The front may actually have a train of waves or small surface lows that travel along the frontal surface to the northeast, each producing a little more cloudiness in the local area but never quite producing rain. The forecaster should be on guard for developing situations which can result in deceleration and prolonged rain or prolonged near-misses. Once a situation like this does develop, the forecaster should watch for a cessation of cold advection into the system and for the strongest winds to move around to the east side of the trough, for then the vorticity is advected out of the deep low, causing it to fill or dissipate, and the weather systems once again regain their normal state of movement from west to east.



(a) Surface Analysis of 0000Z, 10 February 1962.



(b) 500-Millibar Analysis of 0000Z, 10 February 1962.

Figure 9-3. Quasi-Stationary Low-Pressure System.

SHORT-WAVE IMPULSES WITHIN A STATIONARY LONG-WAVE TROUGH

A long-wave trough, by virtue of its wavelength, is often slow-moving or near stationary as if it were being subjected to continuous cold advection. If such a long-wave trough is anchored just off the west coast, a variety of trough and frontal weather may be experienced at Point Mugu. Commonly, a whole series of short-wave (cold) impulses will traverse the pretrough region of rising air to cause brief periods of heavier steady rain in an otherwise scattered rain period. Surface fronts may or may not be analyzed on national facsimile weather maps with each impulse and, since temperatures are usually the same at the surface on both sides of these "fronts," they should more properly be thought of as convergence bands. But since significant weather may be associated with each one, they should be followed and analyzed by local forecasters using some type of consistent annotation. As the air from these surges strike coastal mountains and higher ranges to the northeast, there are sometimes heavy rains. When the whole weather pattern is located a little farther to the north and west, clearing will occur at Point Mugu between each successive impulse but there will be a steady moist southwesterly flow aloft and skies will cloud up quickly with approach of the next impulse.

CLOSED LOWS

When cold advection is very pronounced in the rear of a trough, an isolated cold pool of air and a closed low aloft may form. With the height contours completely closed, no vorticity can be advected out of the low (see appendix A) and the low becomes essentially stationary. Once the closing off of the cold air has taken place, isotherms and height contours become nearly in phase and future movement of the low is usually handled better by the National Meteorological Center barotropic rather than the baroclinic progs.

The position of the cold low is critical in determining its effects on Point Mugu weather. If the low is located just off the coast or over the station, southerly winds on its forward side, when combined with rising motion there and extremely cold temperatures aloft, can bring very heavy and frequent convective showers. The longer the low has remained over water, the greater the quantity of precipitable water vapor. Also, the colder the air aloft, the more unstable the atmosphere becomes, which enhances the production of large cumulus and cumulonimbus towers. The moisture becomes spread vertically throughout the entire depth of the troposphere and thundershowers are not uncommon. Freezing levels often extend down to 3,000 feet or lower and

occasionally during squalls there is snow over the higher terrain in the Point Mugu area.

During the night and early morning hours, there is convergence of air from the land breeze over the relatively warm waters and the thundershowers develop mainly offshore, occasionally moving onto the coast from the area of the Channel Islands and the Sea Test Range. Surface winds during these hours and even during the daytime are often light. During the day, the combination of early heating and a light sea breeze causes most of the showers to occur farther inland and over the mountains.

When the low does start to move back onto the coast, there is sometimes a very sharp dividing line that separates nearly-clear skies over Point Mugu from very heavy and violent convective storms over the Los Angeles and Santa Monica region. This division occurs at the trough line where strong rising motion on the forward side of the low changes to strong sinking motion to the rear of the low. At the same time, 500-mb winds over Los Angeles may be from the southwest while over Point Mugu they may be from the northeast, which is an indication that the rain is ended at Point Mugu. In addition, gusty canyon-channeled, cyclonic northeasterlies may also blow at the surface but these winds should not be interpreted as a true Santa Ana (see under "Cyclonic Santa Anas").

When cutoff lows occur in our general area, they usually form over the Pacific to the northwest as cold air plunges down from the Gulf of Alaska. Another mode by which cutoff lows form that is particularly difficult to predict is when a strong ridge located in the Gulf of Alaska that has shown every tendency of moving eastward onto the coast to produce a Santa Ana suddenly stops and strengthens. As the heights of constant pressure surfaces in the Gulf region rise, the anticyclonic curvature sometimes becomes so great at the crest of the ridge that the strong winds overshoot near the top of the ridge and come back in toward high pressure to form or "dig" a low aloft over the Point Mugu area. This low is commonly referred to as the "cutback" low. As the low continues to deepen and cut back and cold air pours into it from higher latitudes, the low may move off the coast where it will stall, pick up moisture, and produce the unstable showery weather described earlier. One clue that is useful in forecasting the formation of a cutback low is to notice if there is a strong (1,040 mb or higher) stationary surface high located at higher latitudes of the Gulf of Alaska. Presence of this feature is good indication of subsequent cold low formation.

Once the low begins to develop, local winds aloft will go from north to northeast and eventually to southeast and south if the low moves off the coast. During this time, sky conditions will gradually deterKiorate from clear to hazy with occasional stratocumulus and cumulus clouds which, in time, grow in size and number. These signs should be useful, and allow the forecaster to make a change in his outlook if a cutback low was not previously anticipated. Figure 9-4 is a satellite picture showing cloud elements growing progressively larger as air moves toward the coast under the effects of an offshore cold low. It is not unusual for the center of the low itself to be nearly void of any cloudiness. The particular low shown in the figure resulted in variable cloudiness with strong northeast (Santa Ana-like) surface winds. Precipitation from the low was confined to areas further south and east.

NEVADA LOW

When a closed low or deep trough aloft prevails over inland portions of California and the extreme western states, a pronounced surface low frequently develops over southern Nevada and has been informally given the name, "Nevada Low." This low causes a strong onshore pressure gradient to form west of the low center and usually results in strong, gusty west or west-northwest winds over southern California and at Point Mugu, but particularly over California desert regions. Frontal passage may or

Figure 9-4. APT of 1840Z, 13 December 1967 Showing Increase in Size of Cloud Elements Downwind Into Closed Low.

may not have occurred at Point Mugu before formation of the inland low but a well-defined frontal zone is usually observed inland over the desert once the Nevada Low is well established.

Nevada Lows characteristically cause local winds of 20 to 30 knots with moderate turbulence and strong runway crosswinds being the critical factors of concern to pilots and range operations personnel (reference 62). A general absence of cloudiness is usually noted, although cumuliform buildups are often observed over the higher mountains to the north and east and wave clouds are frequently seen over mountains and deserts of the southwest because of the strong west winds. A good example is shown in figure 9-5.

Figures 9-6(a), (b), and (c) show the surface and the 500-mb charts and the surface weather observations, respectively, at Point Mugu for a particularly severe Nevada Low on 13 April 1970. Wind gusts to 43 knots were recorded on that day at Point Mugu, and visibilities were reduced to 5 or 6 miles in blowing dust for much of the day. As shown on the surface observations [figure 9-6(c)] and as is typically the case, the strong west winds begin in midmorning, reach their peak strength in afternoon, and then diminish at night. This is exactly the same pattern noted for the typical sea breeze. Thus, during Nevada Low situations, the normal daytime sea breeze is greatly enhanced by the synoptic-scale onshore gradient so that daytime winds are strong. In early morning, shallow cold air drainage or land breeze drift may weaken or temporarily reverse the airflow at the surface.

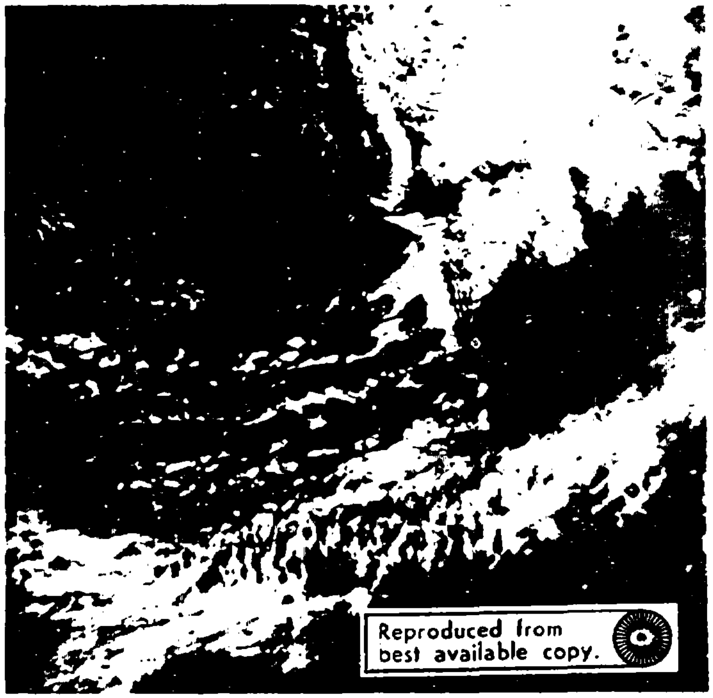
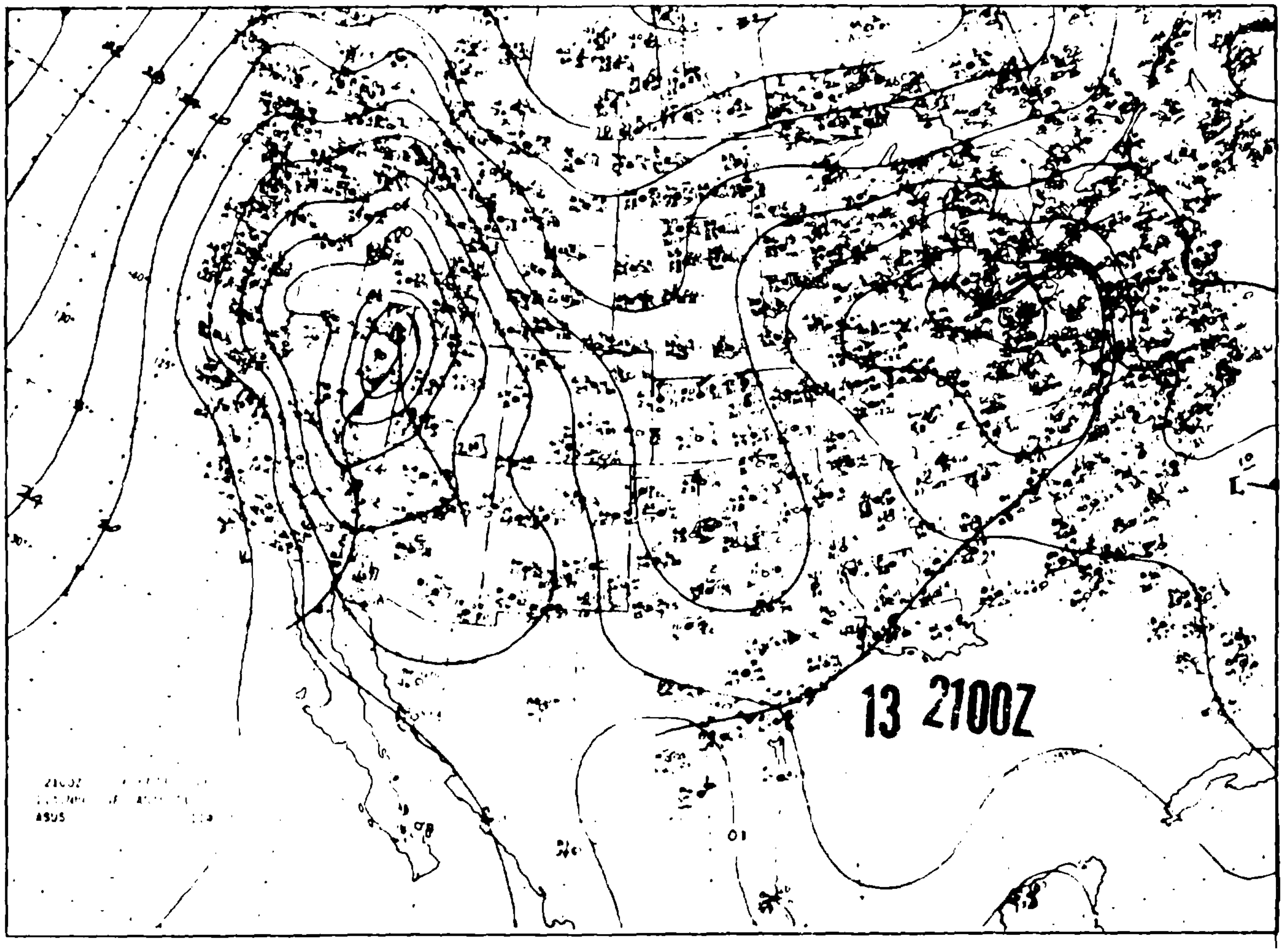


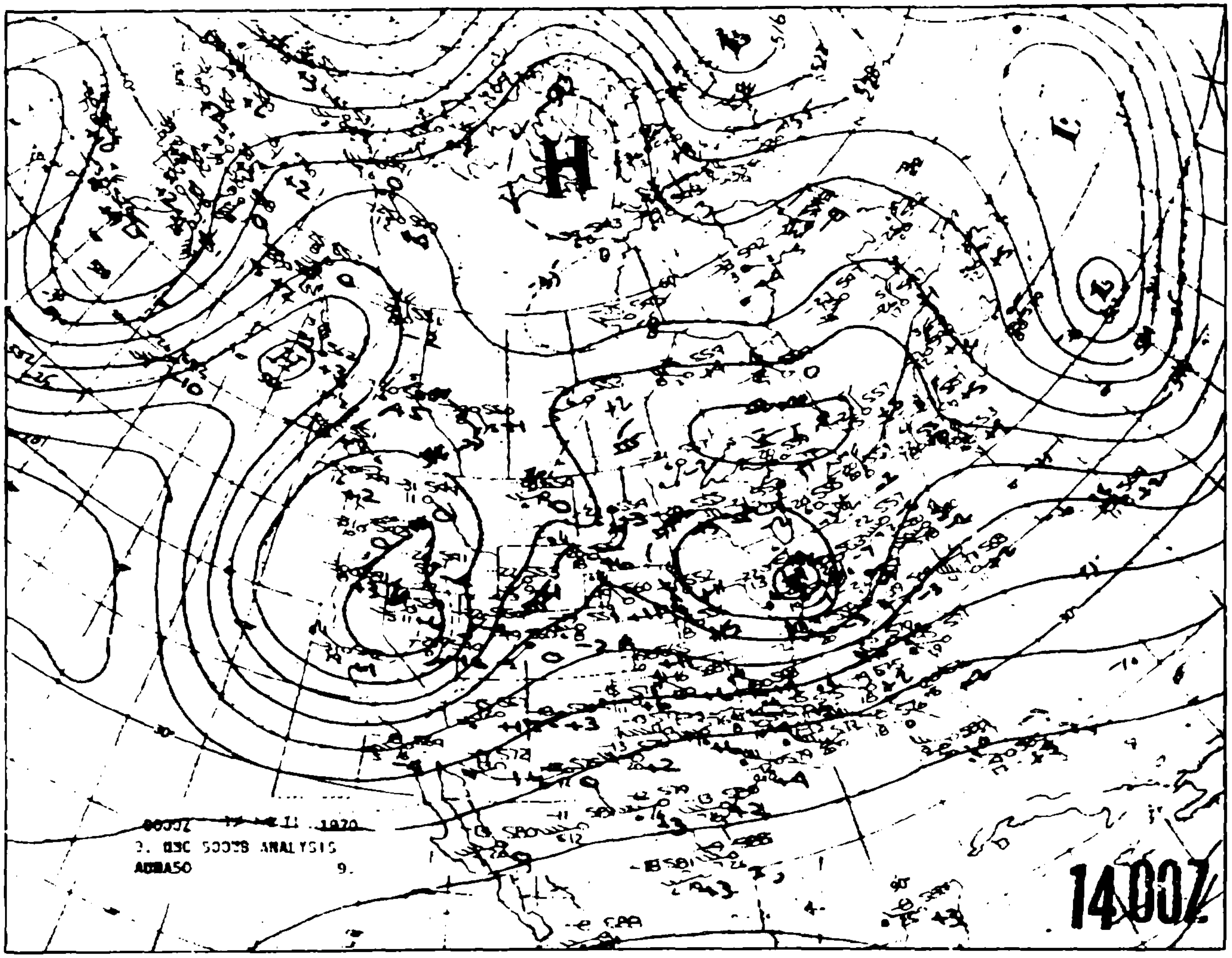
Figure 9-5. Wave Clouds Over Desert During Nevada Low.

FIGURE 9-6



(a) National Meteorological Center Surface Analysis of 2100Z, 13 April 1970.

Figure 9-6. Examples of Strong Nevada Low.



(b) National Meteorological Center 500-Millibar Analysis of 0000Z, 14 April 1970.

Figure 9-6. Continued.

FIGURE 9–6

OPNAV FORM 3140-8 (REV. 8-61) 0107-711-0000

DEPARTMENT OF THE NAVY
SURFACE WEATHER OBSERVATIONS
(LAND STATIONS)

WBAN FORM 10A

Station: PMR POINT MUGU CALIFORNIA

Date: 13 APRIL 1970

Type	Time (LST)	Sky and ceiling (Hundreds of feet)	Visibility (Statute miles) Surface	Visibility Tower	Weather and obstructions to vision	Sea level press. (mbs.)	Temp (°F)	Dew pt (°F)	Wind Direction	Wind Speed	Wind Character	Altimeter setting	Remarks and supplemental coded data	Initials
R	0057	300Φ	8			115	53	47	29	11		986	307 1002 MAG 28	JB
R	0157	300Φ	8			108	54	47	26	07		984	MAG 25	JB
R	0257	300Φ	8			108	53	47	25	10		984	MAG 24	JB
R	0357	300Φ	8			112	53	47	26	12		985	503 1002 53 MAG 25	JB
R	0457	15Φ120Φ300Φ	8			105	53	47	27	14		983	MAG 26	JB
R	0557	15Φ120ΦE300⊕	5		BD	112	53	46	02	01		985	MAG 01	TS
R	0657	15ΦE200Φ	5		BD	118	53	49	23	02		987	307 1502 MAG 22 RADAT 33 098	RG
R	0757	18Φ	5		BD	118	57	45	27	08		987	MAG 26	RG
RS	0857	E18Φ	5		BD	118	58	40	28	12		987	MAG 27	RG
S	0930	18Φ	5		BD				29	10		986	MAG 28	RG
R	0957	15Φ	5		BD	125	58	37	28	12	G20	989	308 1500 53 MAG 27	RG
R	1057	15Φ 300-Φ	6		BD	122	60	38	28	15	G26	988	MAG 27	LT
R	1157	15Φ300-Φ	6		BD	118	60	39	28	22	G31	987	MAG 27 RADAT 10064/3	RG
R	1257	300-⊕	6		BD	115	60	40	28	20	G34	986	812 1007 MAG 27	RG
R	1357	15Φ300-⊕	5		BD	105	58	43	27	28	G40	983	MAG 26	RG
R	1457	300 ⊕	5		BD	105	60	40	27	26	G38	983	MAG 26	PG
R	1557	15Φ 300-⊕	5		BD	108	58	41	28	24	G40	984	507 1107 60 MAG 27	RG
R	1657	15Φ 300 ⊕	5		BD	112	57	42	28	22	G35	985	MAG 27	LT
R	1757	15Φ 300-⊕	5		BD	118	54	40	28	28	G38	987	MAG 27	RG
R	1857	300-Φ	8			125	54	38	28	24	G36	989	37 1008 MAG 27	WK
R	1957	300-Φ	8			132	53	35	28	25	G35	991	MAG 27	PA
R	2057	300-Φ	8			139	53	35	29	23	G28	993	MAG 28	WK
R	2157	O	10			142	53	35	29	22	G32	994	119 60 MAG 28	PA
R	2257	O	10			145	53	36	29	18	G21	995	MAG 28	WK
R	2357	O	10			149	53	35	29	17	G25	996	MAG 28	PA

SUMMARY OF DAY (MIDNIGHT TO MIDNIGHT)

24 HR MAX TEMP (°F) 66	24 HR MIN TEMP (°F) 67	24 HR PRECIP WATER EQUIV (Ins.) 68	24 HR SNOWFALL UNMELTED (Ins.) 69	SNOW DEPTH (Ins.) 70	PEAK GUSTS Speed 71	PEAK GUSTS Direction 72	PEAK GUSTS Time 73	74	75	76	77	SKY COVER Sunrise to sunset 78	SKY COVER Midnight to midnight 79	80	81
60	52	0	0	0	43	W	1509					7	5		

PRECIP AND THDRSTM 82	BEGAN 83	ENDED 84	WATER TO VISION 86	BEGAN 87	ENDED 88
			H	~~0550~~	~~1330~~
			BD	~~1330~~	1850
				0550	

90 REMARKS, NOTES AND MISCELLANEOUS PHENOMENA

FASTEST RECORDED ONE MINUTE WIND SPEED | ASSOCIATED DIRECTION | TIME

(c) WBAN Surface Hourly Reports for Point Mugu for April 1970.

Figure 9-6. Concluded.

Nevada Lows occur primarily during the cooler months, particularly during the late winter and early spring months of March, April, and May. It is during this time of year when the Pacific High becomes very strong and the desert interior begins to heat intensely, greatly aiding the development of the inland low and the strong onshore pressure gradient. At Point Mugu, the month of April shows the highest frequency of windy days (days with gusts of 20 knots or over) (reference 31), most of which are probably due to Nevada Low-type situations with strong onshore flow. Figure 9-7 presents a simple way of estimating the strength of Point Mugu's westerly sea breeze during Nevada Low conditions using the 1,000-meter winds at 1200Z at Vandenberg AFB. The graph may also be applied more generally to any sea breeze during the spring months.

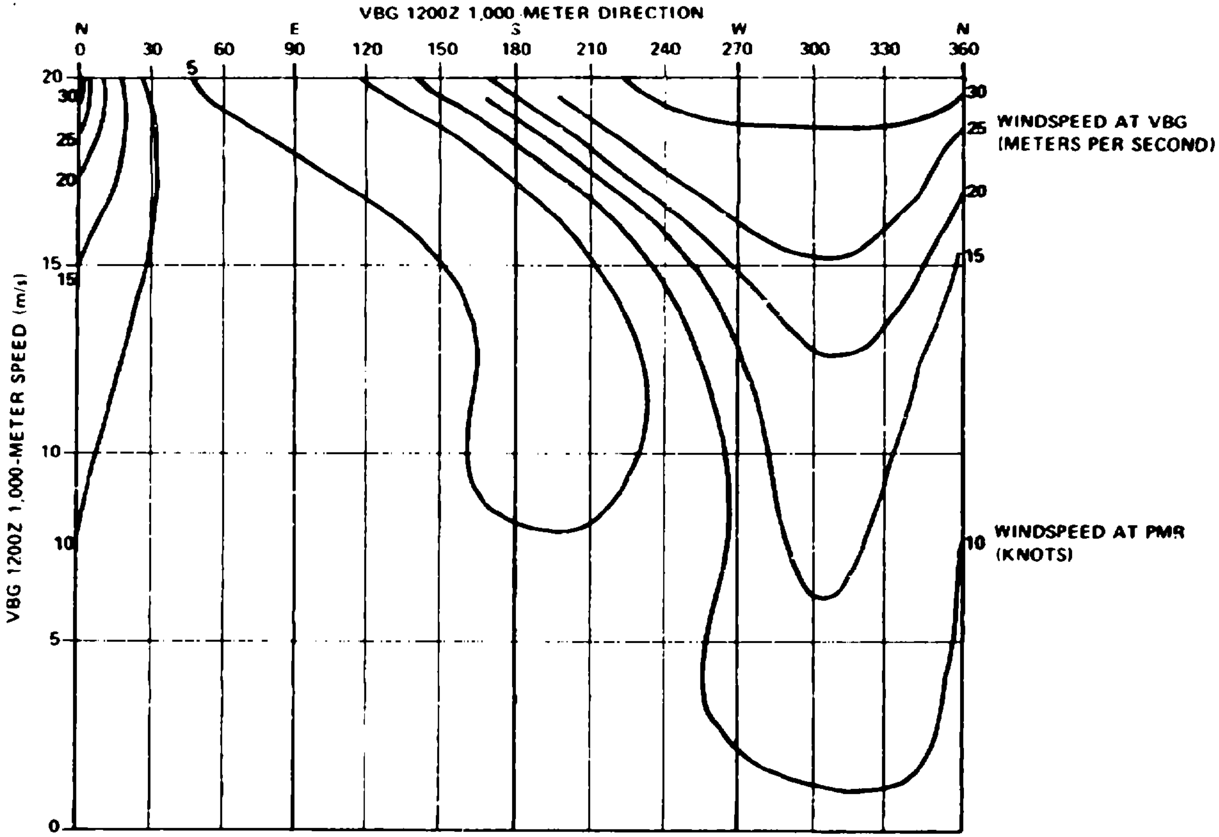
SPLIT IN WESTERLIES

The upper airflow and belt of westerlies are not always a smooth, undulating feature which cover the midlatitudes from north to south. Occasionally these westerlies split into a northern branch and a southern branch, each with its own region of strongest winds or jet stream. A split in the westerlies is very important for forecasting at Point Mugu because the number and positions of troughs and ridges are frequently different in each branch. A low-latitude branch of westerlies is often associated with moisture and low-pressure systems modified in the tropics which approach the local area from the southwest. The heavy rains of January 1969 were embedded in a southern branch of westerlies as shown in figure 9-2(b).

It is interesting to note that a University of California, Los Angeles study on precipitation patterns over the western states (reference 63) has revealed various irregularities in the timing and degree of the winter rainfall maximum as it progresses southward through Baja California. It may be that such patterns are, at least in part, due to frequent splits in the westerlies leaving Baja California under a strong southwest flow aloft in the vicinity of the subtropical jet stream during the end of December and beginning of January when the northern part of coastal Baja California records its peak in the winter rainfall maximum. Coastal southern California, on the other hand, does not reach its peak in the winter rainfall maximum until February, indicating a possible tendency for seasonal pulsations in the southwest thrust of the jet stream and westerlies (references 63 and 64).

Generally, the split in the westerlies does not exist all the way around the Northern Hemisphere. A split in one particular region such as the eastern Pacific or southwestern United States seems to diminish the reliability of National Meteorological Center numerical progs in our latitude. Thus the individual forecaster must rely heavily on his own skill and take extra care in arriving at his forecast.

FIGURE 9–7



NOTE: Isopleths indicate approximate magnitude of maximum hourly mean vector surface wind at Point Mugu, for afternoon onshore winds (Point Mugu wind in *knots*).

Figure 9-7. Maximum Sea Breeze Strength at Point Mugu During Spring Months as a Function of Vandenberg AFB Wind Direction and Speed, March - May 1949 - 1964. (From reference 40.)

INDEX CYCLE

In general, the atmosphere fluctuates between high- and low-zonal-index conditions for periods of 2 weeks to 2 months. Under a high-zonal-index circulation, the upper-level winds are blowing almost from west to east with very small north-south components. Troughs and ridges and their surface counterparts are then relatively shallow and fast-moving. Under a low-zonal-index circulation, the winds aloft are very meridional and troughs and ridges have large amplitudes, which sometimes cause isolated highs and lows. In such cases, isolated pools of warm air may be located far to the north; pools of cold air may be located over subtropical regions.

For Point Mugu, high-index conditions bring frequent passages of weak to moderate frontal systems with short periods of rain separated by periods of clear conditions or extensive periods of stratus and fog. Frontal systems move rapidly and are steered by the upper-level winds. Winds at the surface are almost always onshore and are fairly strong. Temperatures are neither very cool nor very warm. With a low index, weather conditions are determined by the position of the upper-level trough or ridge with respect to the local area. When dominated by a ridge, Point Mugu can have clear, smoggy and warm weather interspersed with possible Santa Ana winds; when dominated by a trough, Point Mugu can have frequent rains and southeast winds separated by brief periods of very cool, mostly clear conditions with brisk west winds. Frequently during periods of low index, blocking highs develop aloft which are very persistent and stationary and can result in a split in the westerlies such that there is a strong zonal flow both to the north and south of the block. Storms will not be able to penetrate the blocking high but will travel to the north or well to the south of it. The forecaster should always be alert to any change in the zonal index as a forerunner of a change in the general weather pattern at Point Mugu.

MID-NOVEMBER RAIN ANOMALY

A strange climatological abnormality was recently found to exist at Point Mugu and other locations in the western United States. Results of a PMR study (reference 42) show that the middle 10-day period in November (for 1946 to 1965) has been particularly susceptible to rainfall when compared with other 10-day periods during the year at Point Mugu, and slightly higher in frequency of days with measurable rain than the last two 10-day periods in January. For the time of the year, and compared with 10-day periods immediately before and following, the mid-November peak stands out as a striking anomaly.

In addition to the frequency of rainy days, there may also be a tendency in recent years for these rains to be unusually heavy. Thus mid-November would appear to be a poor time to schedule operations and outdoor ceremonies.

Briefly, the November anomaly appears to be due to a combination of a first and early penetration of the westerlies to lower latitudes (reference 64), warm surface waters off the southern California coast, and influxes of tropical air from the still relatively active intertropical convergence zone. It is of interest that an independent study (reference 17) for a similar data period 1951 through 1965, showed the greatest 700-mb height falls for any 5-day period during the year over the far western states occurred 12 to 16 November, consistent with the mid-November rains at Point Mugu. Studies of rainfall patterns over much longer data periods (1899 to 1967) show no significant secondary peak in the winter rainfall maximum during the month of November even when analyzed by harmonic analyses (reference 63). Thus it appears that there are wide fluctuations in "seasonal" patterns of rainfall from decade to decade and century to century with long-term variability of sea surface temperatures probably being a critical factor.

THUMB RULES AND FORECASTING AIDS ON OTHER CYCLONIC AND RAIN-PRODUCING CIRCULATIONS THAT AFFECT POINT MUGU

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
A southerly branch of westerlies or southwesterlies often brings heavy rains to Point Mugu.		✓		9-3, -5, -8
Cold advection into the rear of a trough causes deepening.	✓			9-8
Deepening of a low causes it to slow down.		✓		9-8
Cessation of cold advection indicates the system will speed up.		✓		9-8
Long waves are slow-moving or stationary.	✓			9-10
Long waves are traversed by fast-moving short-wave impulses which cause temporary deepening.	✓			9-10
Cutoff lows show little or no movement.		✓		9-10
A strong (1040 mb or more) stationary surface high in the northern Gulf of Alaska is a good clue to cold low or trough formation over southern California and subsequent rain.		✓		9-11
Increasing stratocumulus and cumulus is a sign of an approaching trough or development of a cold low.	✓			9-12
When upper winds over Point Mugu shift from SW to NE, it is an indication that rain is ended at the Station.		✓		9-11
Nevada Lows cause strong westerly winds locally.	✓			9-12, -13
Cold lows over water often have nearly clear centers.			✓	9-12
The index cycle may provide changes in flow patterns which make it easier to make long-range forecasts or outlooks.			✓	9-19
Storms or fronts do not penetrate blocking highs.	✓			9-19
Rain is likely at Point Mugu during the middle 10 days of November.	✓			9-19

CHAPTER 10. TROPICAL AIR

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CHAPTER 10

INFLUX OF TROPICAL AIR MASSES

Tropical air comes from the warm oceanic regions of low latitudes and assumes the characteristics of high temperatures and very high humidity. In the source regions, the air extends up from the surface, but at Point Mugu it is found chiefly in the middle and upper troposphere.

Movement of Tropical Air Into Point Mugu Area

Whenever the wind blows out of the tropics, tropical air may be advected to higher latitudes. At the surface, winds rarely blow away from the equator in tropical latitudes due to the constancy of the tradewinds but at the higher altitudes, moist, warm air frequently makes its way poleward around the west side of subtropical anticyclones. Such airflow is responsible for the occurrences of tropical air along the west coast. On a yearly basis, tropical air at Point Mugu occurs most frequently in summer. It comes with southeasterly flow from the Gulf of California and the Gulf of Mexico as it moves around an upper level high over the desert regions of the west. Occasionally tropical storms or their remnants move northward toward California bringing appreciable amounts of tropical air, sometimes even down to the surface. During the cooler months, modified tropical air sometimes becomes entrained in the southerly flow ahead of deep troughs embedded in the westerlies. In such cases, the air comes largely from the Hawaiian area and may result in heavy rains such as those of January 1969.

EFFECTS ON WEATHER

Sky Conditions

The most important result of an influx of tropical air at Point Mugu is the appearance of middle and high clouds, particularly altocumulus during the summer months. In fact, during the summer months, nearly every occurrence of cloudiness other than normal stratus may be directly attributable to tropical air and southeasterly flow aloft. While there are no definite cause-and-effect relationships substantiated, it appears that the presence of the moist air and midclouds aloft affects the outgoing radiation balance in such a way that stratus coverage is reduced along the coastal strip. The Weather Service

Forecast Center in Los Angeles uses this observation as an informal forecasting rule but it has not been verified that it applies to the immediate Point Mugu area and the offshore waters. Other factors such as the position of the inland, heat-induced thermal trough are also affected by the higher cloudiness. It seems likely that the heavier the tropical overcast and the nearer to the surface the humid air descends, the less persistent will be the stratus coverage.

During the cooler months, clouds of tropical origin are indistinguishable from frontal and pre-trough cloudiness.

Precipitation and Thunderstorms

An influx of tropical air in summer frequently results in thunderstorms over the desert and mountain areas where heating and orographic lifting are at a maximum. Occasionally in late summer, (reference 18) these thunderstorms drift or form over southern California coastal sections including Point Mugu, although they are not always immediately detected because of a low stratus cover. However, hourly reports from nearby stations such as Burbank (BUR) or others in the Los Angeles Basin will usually show some clue to the presence of these storms. The outputs from the latest rawinsondes from Point Mugu and San Nicolas Island should always be inspected in summer for the presence of southeasterly winds or the presence of appreciable (~40%) moisture above the normal surface-based marine layer.

In most instances of heavy summertime influx of tropical moisture aloft, thunderstorms will not occur at the coast because of the absence there of sufficient heating to produce large convective clouds. On the other hand, sprinkles of rain falling from a deck of altocumulus or altostratus are much more common and occur several times each summer. Again, the occurrence of southeasterly winds between 10,000 and 20,000 feet along with high (>40%) relative humidities as shown on latest soundings are perhaps the best tools the forecaster has to predict these infrequent summer showers. Satellite pictures are also useful since they sometimes show the presence of masses of heavy midclouds to the south and east of Point Mugu before they are observed locally. Such cloudy and showery periods are generally of short duration at Point Mugu, usually less than 24 hours, and often end abruptly when the upper winds shift from southeast to southwest. By comparison, winter thunderstorms in the local area occur almost exclusively in the cold, unstable air associated with active fronts and upper lows (reference 18).

Temperature and Humidity

On rare occasions only does tropical air reach the surface at Point Mugu, when it results in abnormally high temperatures and dewpoint.

TROPICAL STORMS

Frequency

Before the advent of meteorological satellites, it was generally believed that only a few tropical storms formed or moved through the eastern North Pacific each year during the tropical storm season, May to November. By the mid-1950s, the amount of ship activity and reports had increased to the point where the annual number was raised to about 10 (reference 65). Since that time, increasingly excellent satellite coverage has raised the average further (see table 10-1, reference 66) and as many as 19 confirmed tropical storms were recorded in a single year, making the Northeast Pacific one of the most active regions in the world. The Müirhead and facsimile pictures received and recorded at Point Mugu via our APT equipment have frequently formed the basis for recognition, study, and subsequent issuance of warnings by Fleet Weather Central, Alameda which has the responsibility for forecasting and advising the Navy on tropical storm activity in the eastern Pacific. Even with the excellent coverage and high resolution satellite pictures currently available, several additional tropical disturbances go unrecognized by officials each year because of lack of confirmed reports from ships in their path. Figure 10-1 shows one such disturbance which, according to standard charts relating cloud pattern to storm intensity, may have been of tropical storm intensity (maximum sustained winds of 34 to 64 knots). (References 67 and 51.)

Preferred Paths

Most of the Northeast Pacific tropical storms form a few hundred miles off the west coast of Mexico between 10° and 20° north latitude over very warm waters. The disturbances probably originate as easterly waves that travel across the Mexican peninsula. They are fed directly through the southern half of the storm by the massive moisture and cloudiness of the ITCZ (Intertropical Convergence Zone) which, in summer, is located in the northeast Pacific at around latitude 10° north. During the midsummer months, the storms move northwestward and westward, paralleling the coast of Mexico (reference 68) and expend their energies at sea and over the open shipping lanes. During the early and especially during the late season months, several storms usually curve to the northeast and cross the Mexican mainland coast or Baja California where they pose a threat to coastal communities and eventually die over land. In so doing they frequently result in impulses of tropical moisture that reach the local area. Figures 10-2(a) through (h) show the tropical cyclone tracks for individual months for the period 1949 through 1966 (from DeAngelis, 1967, reference 68). Figure 10-3 shows the paths of storms in the Hawaiian Island area.

Table 10-1. Frequency of Eastern North Pacific Tropical Cyclones, 1958-1969

(Figures indicate the number of cyclones *started* each month; a few continued into the following month.)

Year	June		July		August		September		October		November		TOTAL	
	Tropical Storm*	Hurri-cane**	Tropical Storm	Hurri-cane	Tropical Storm	Hurri-cane	Tropical Storm	Hurri-cane	Tropical Storm	Hurri-cane	Tropical Storm	Hurri-cane	Tropical Storm	Hurri-cane
1958	1	1	2	2	1	0	1	2	2	0	0	0	7	5
1959	2	0	3	0	3	0	0	2	1	1	0	0	9	3
1960	2	0	0	1	0	2	0	1	0	2	0	0	2	6
1961	0	1	4	0	1	0	1	0	2	0	1	1	9	2
1962	0	1	1	0	2	0	3	0	0	1	0	0	6	2
1963	0	1	0	2	0	0	4	0	0	1	0	0	4	4
1964	0	0	2	1	2	0	1	0	0	0	0	0	5	1
1965	4	0	0	0	2	1	3	0	0	0	0	0	9	1
1966	0	1	0	0	0	4	4	2	2	0	0	0	6	7
1967	2	1	4	0	2	2	2	2	1	2	0	0	11	7
1968	1	0	4	0	5	3	1	2	2	1	0	0	13	6
1969	0	0	2	1	1	1	2	1	1	1	0	0	6	4
TOTAL	12	6	22	7	19	13	22	12	11	9	1	1	87	48
Average	1.0	0.5	1.8	0.6	1.6	1.1	1.8	1.0	0.9	0.7	***	***	7.2	4.0

*Maximum intensity was Tropical Storm (winds of 34 to 63 knots)

**Maximum intensity was Hurricane (winds of 65 knots or higher)

***Less than 0.5

Note: Information based on reference 66, Climatological Data, National Summary, Annual (13th issue of each yearly volume).

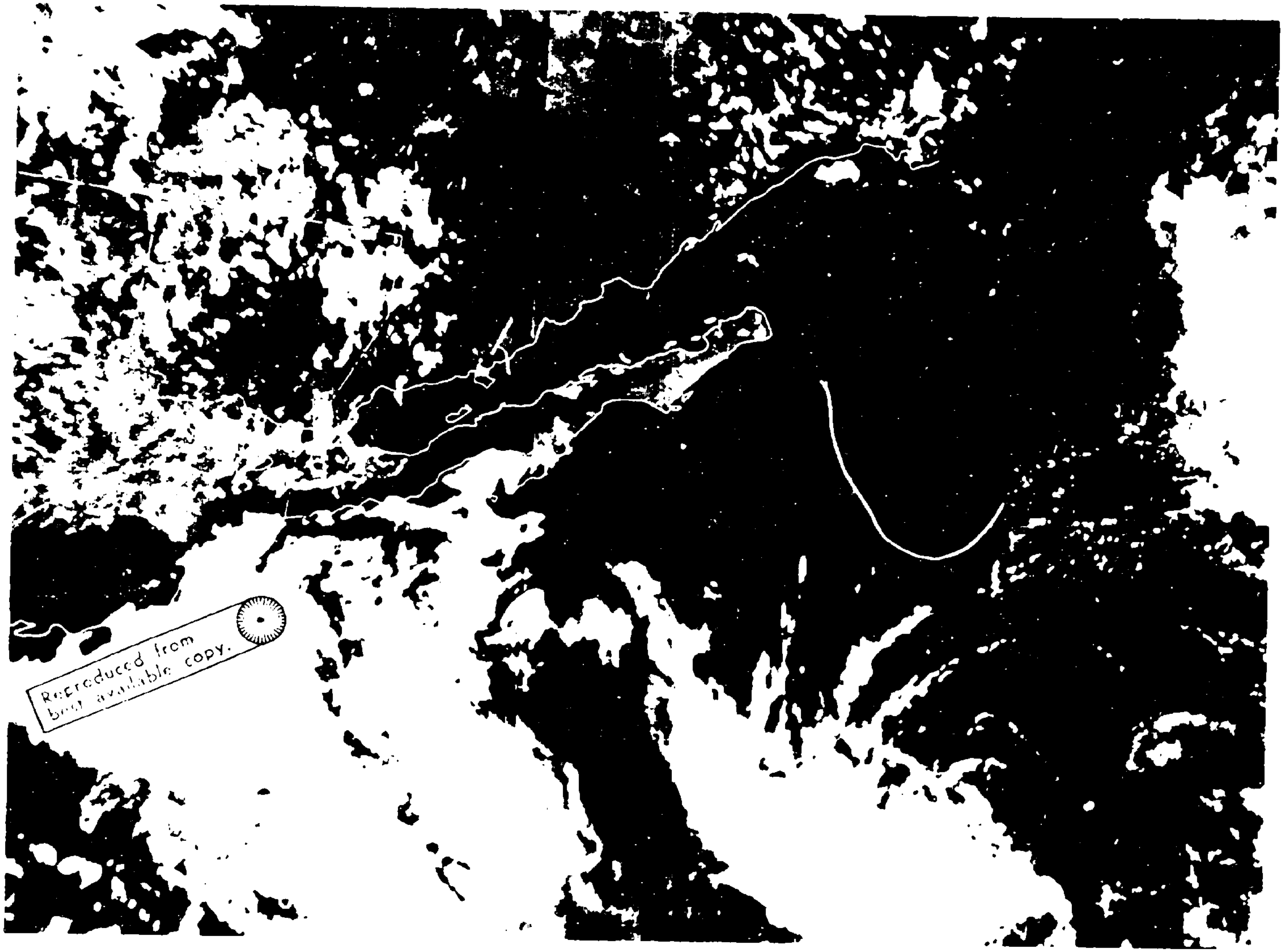
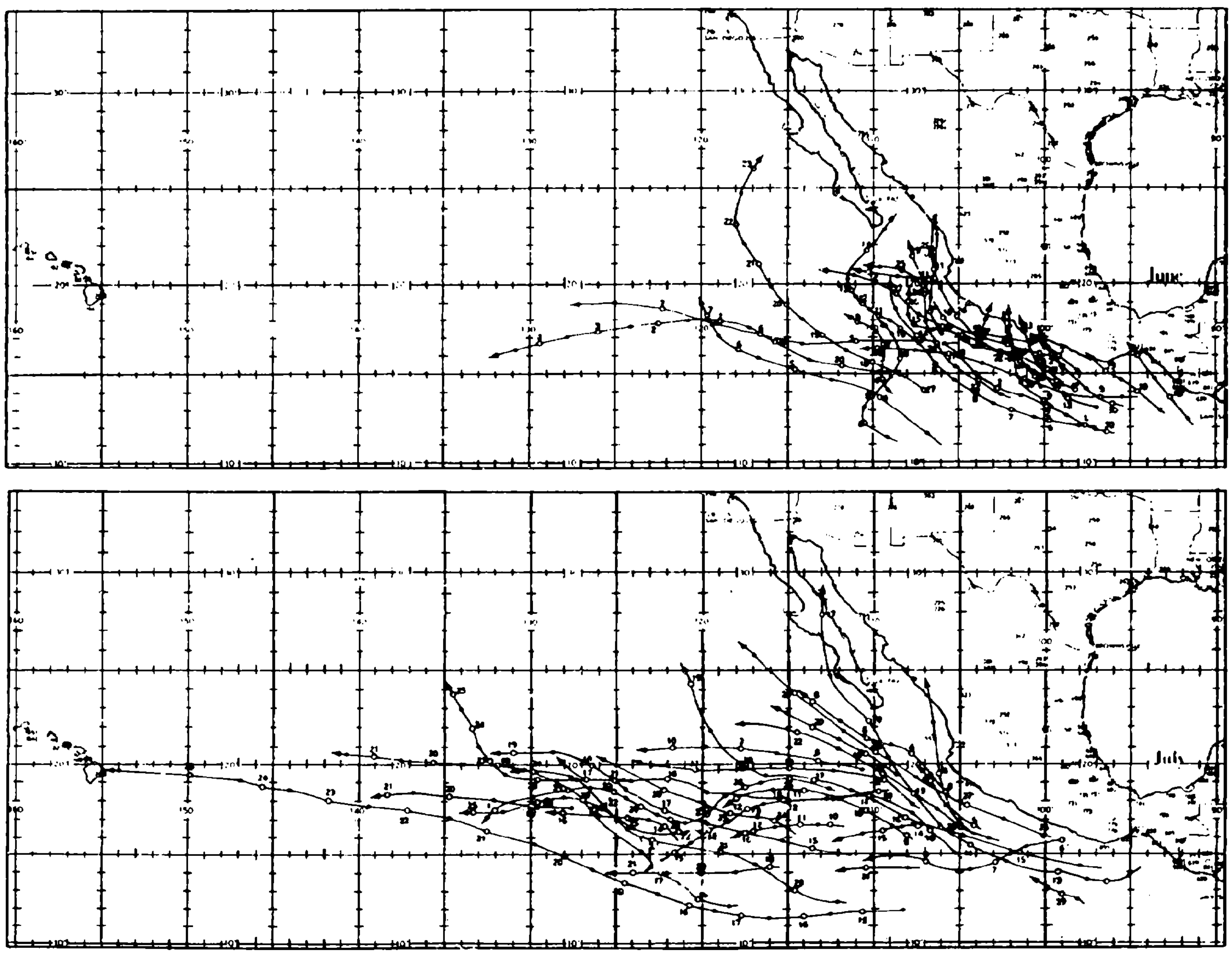


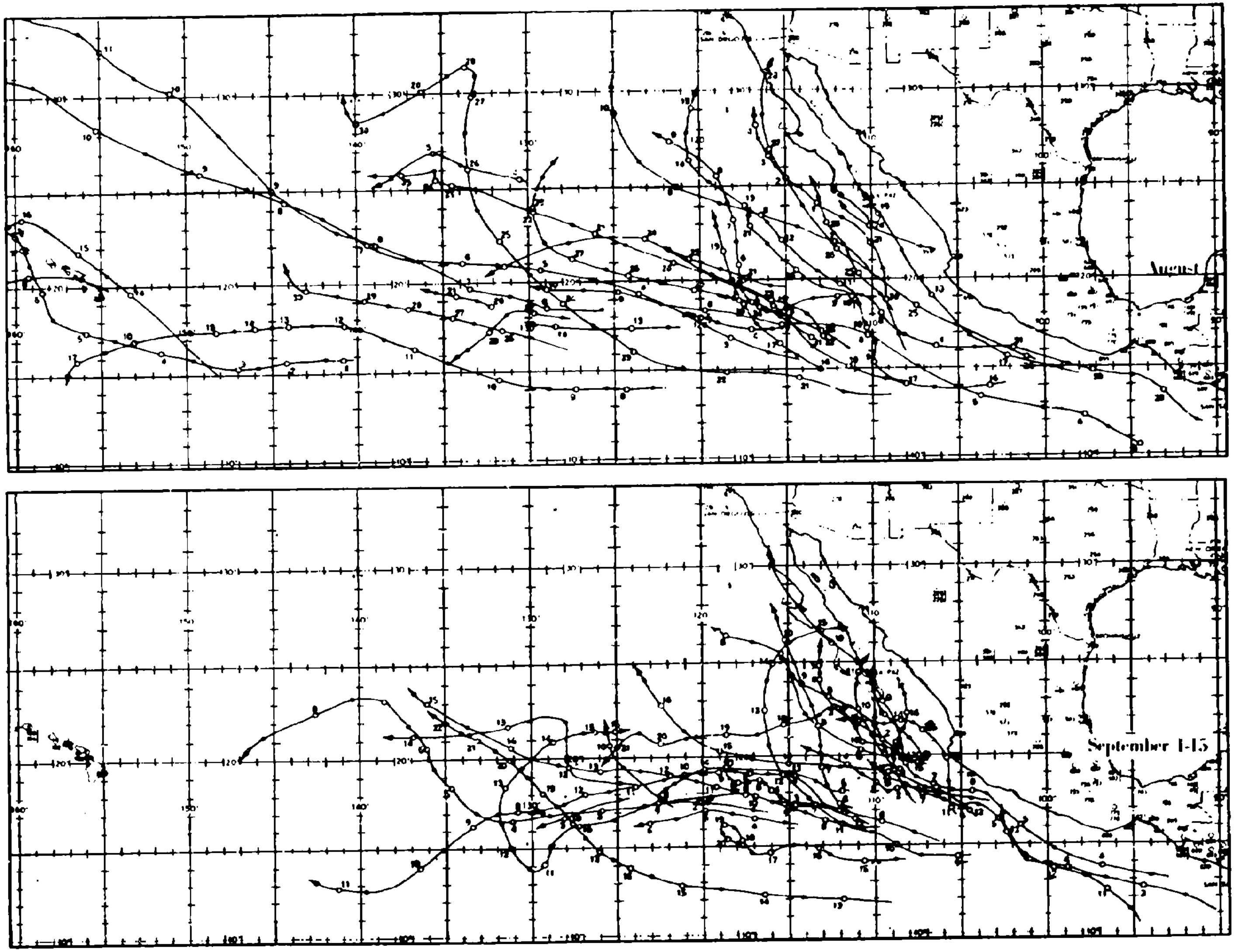
Figure 10-1. Officially Unrecognized Tropical Disturbance Centered About 200 mi [illegible] Southwest of La Paz, Mexico, by Nimbus 3 APT, 18272, 15 September 1969



(b)

(a)

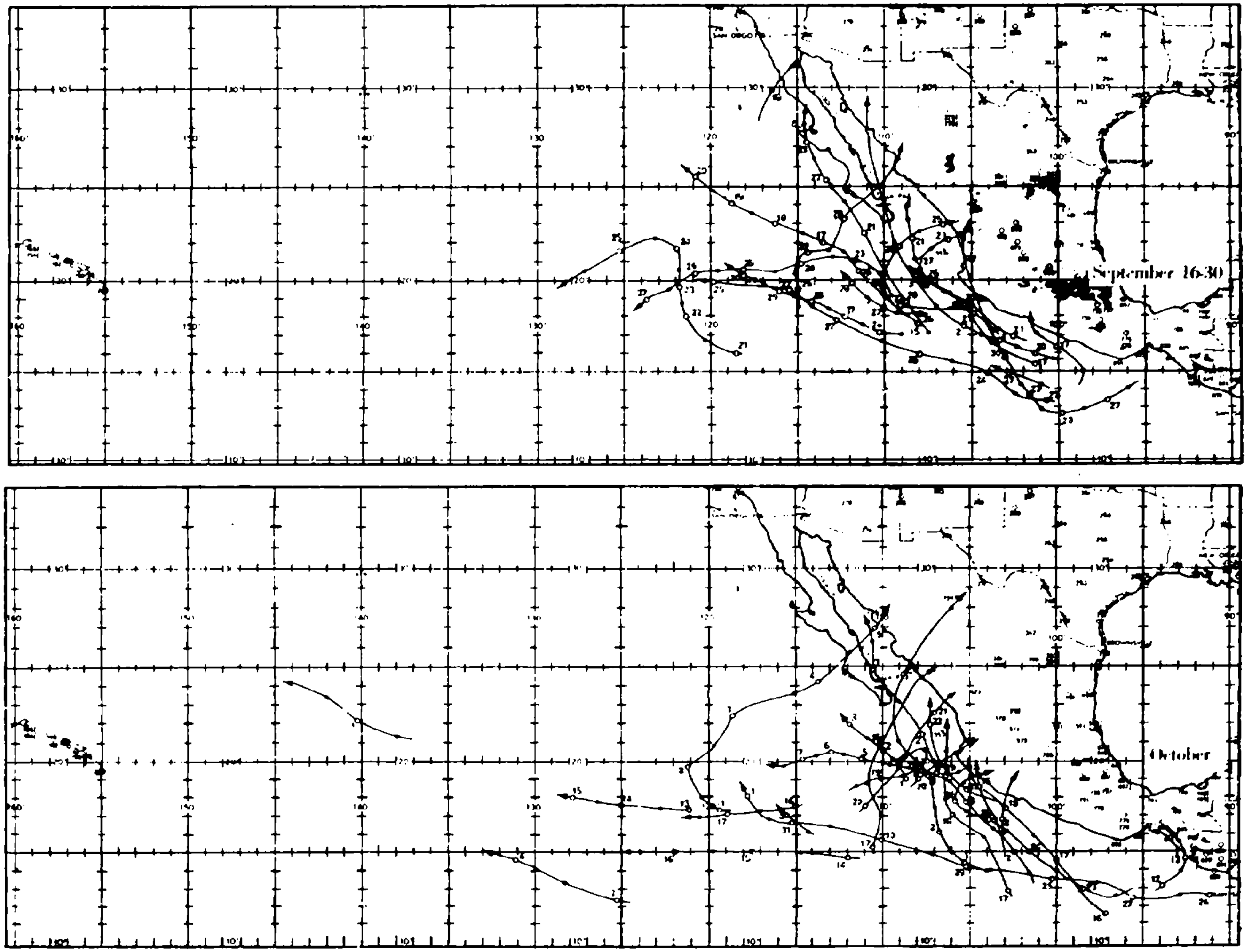
Figure 10-2 (a and b). Tropical Cyclone Tracks in Northeast Pacific, June and July. (From reference 68)



(d)

(c)

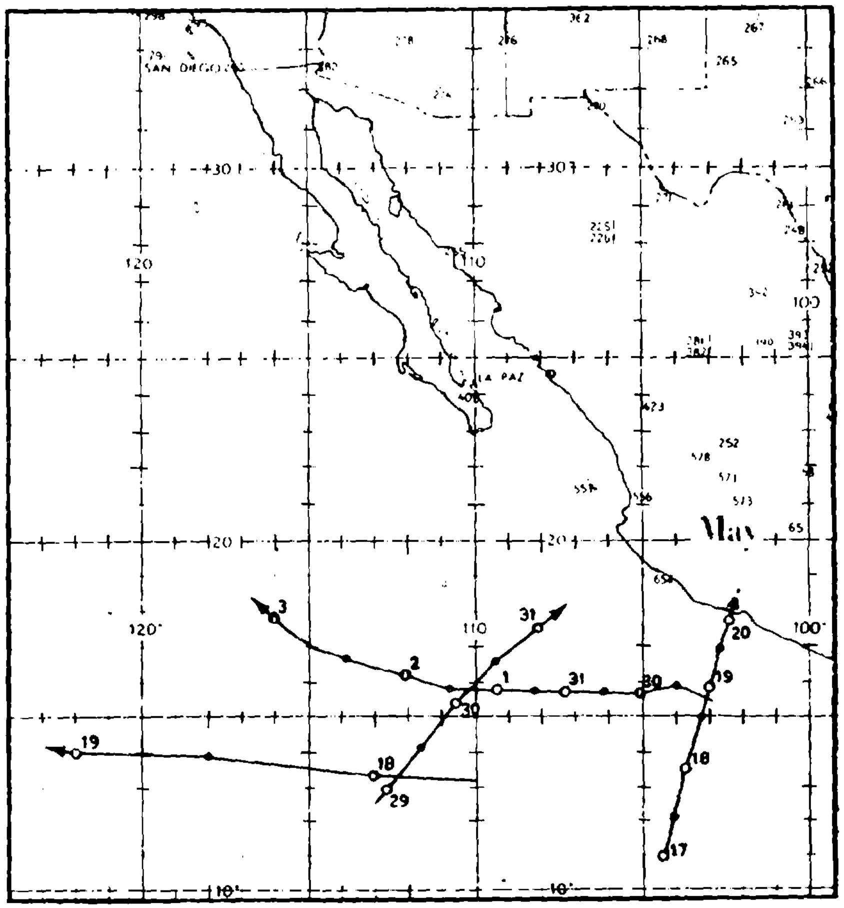
Figure 10-2(c and d). Tropical Cyclone Tracks in Northeast Pacific, August and September.
(From reference 68)



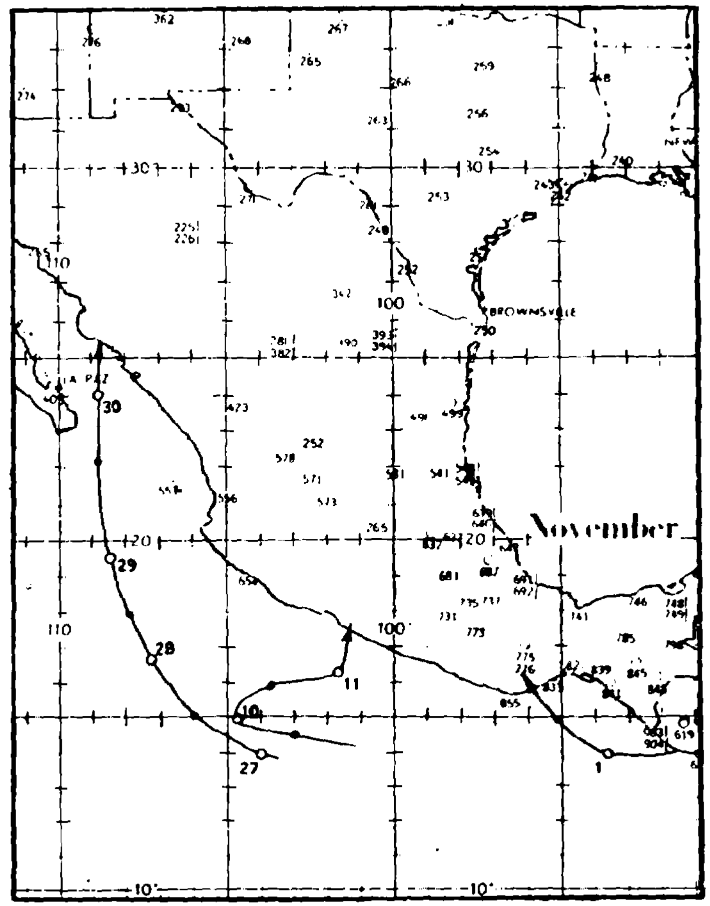
(f)

(e)

Figure 10-2(e and f). Tropical Cyclone Tracks in Northeast Pacific, September and October.
(From reference 68)



(g)



(h)

Figure 10-2(g and h). Tropical Cyclone Tracks in Northeast Pacific, May and November.
(From rererence 68)

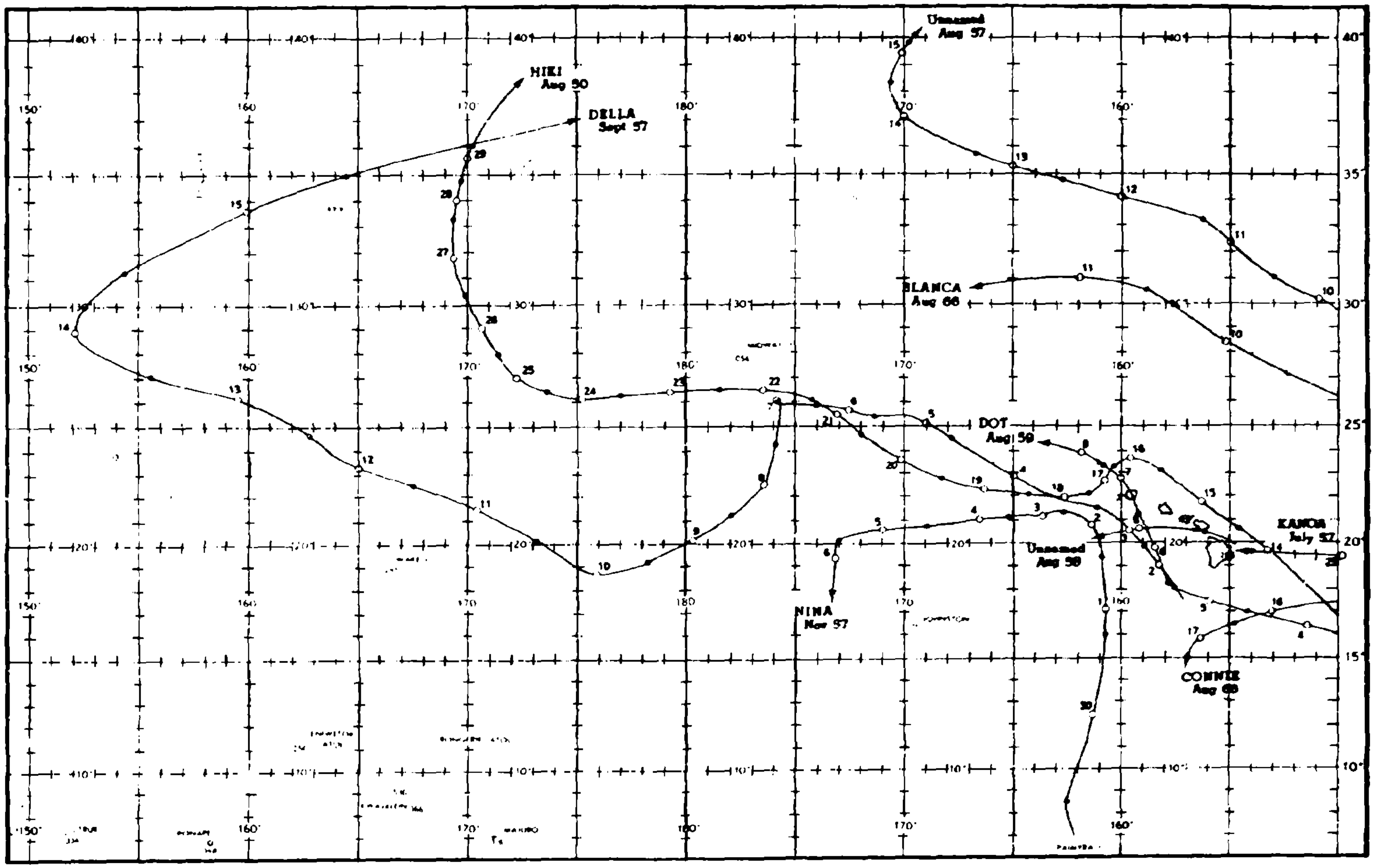


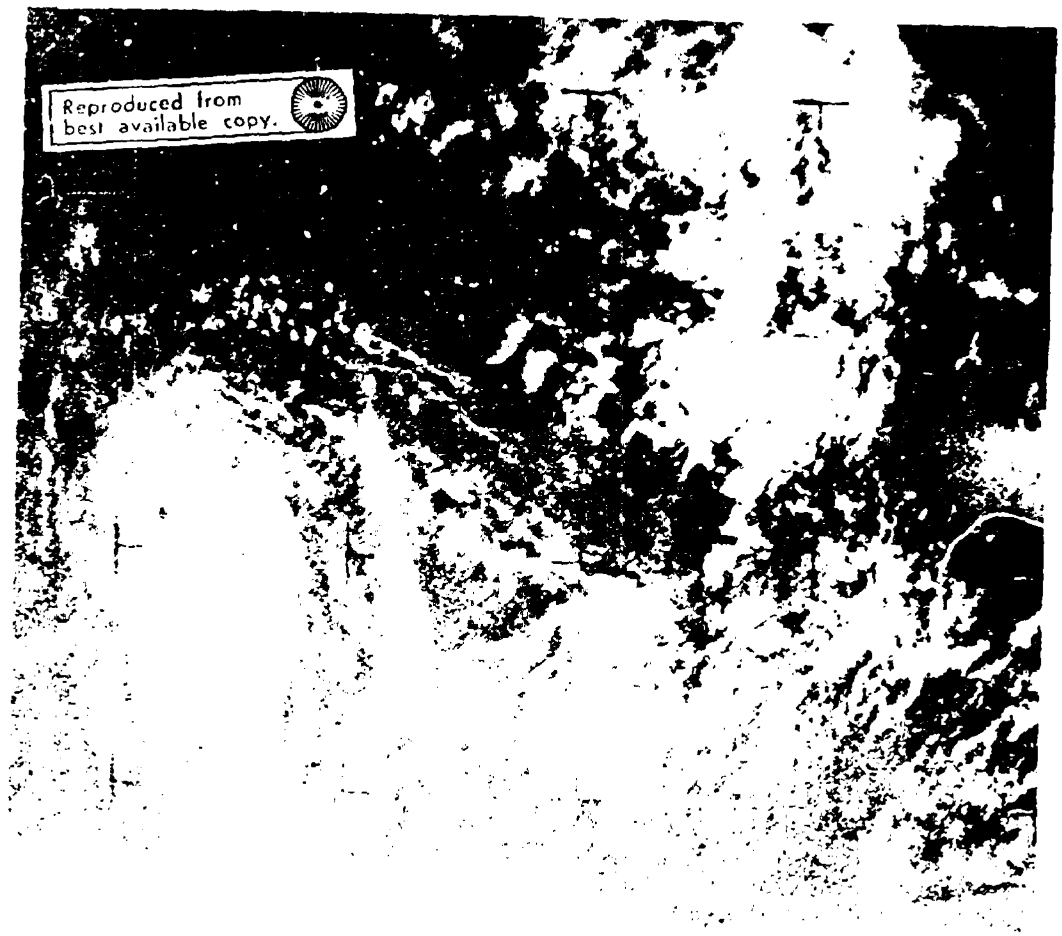
Figure 10-. Eastern North Pacific Tropical Cyclones in Hawaiian Island Region. (From reference 68)

Closest Approach to Point Mugu

Tropical storms or their remnants occasionally travel far to the north and affect southern California. The most notable example occurred on 25 September 1939 when a tropical storm crossed the southern California coastline near Los Angeles and produced high winds and surf and very heavy rains (up to 13 inches at Mt. Wilson). More recently, well defined hurricane Lily was photographed at the time of her greatest intensity [figure 10-4(a)] moving northward toward the U.S. coastline on 7 September 1967. The early morning sun revealed a dramatic photograph of a hurricane's eye. It dissipated as it moved northwestward, and advisories were finally discontinued as the storm was considered to be no longer in existence. Following the end of this official recognition, Lily's remains were still clearly visible as seen by satellite pictures received at Point Mugu on 12 September [figure 10-4(b)]. Spiraling bands of predominantly low clouds are apparent to the southwest of the local area. The remains of this storm brought variable thick low clouds, drizzle, and very high dewpoints to Point Mugu.

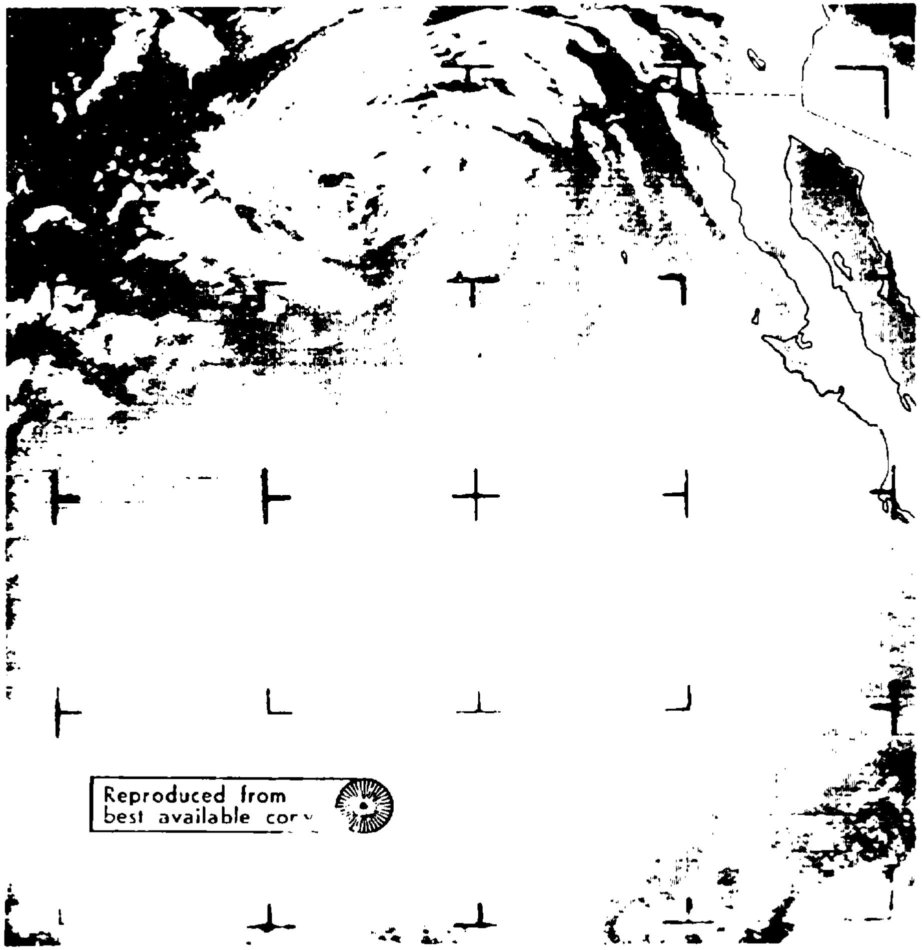
Intensity and Duration

While tropical storms in the northeast Pacific are rather frequent during the summer months, they are not as intense as their counterparts in the Atlantic and western Pacific, where about one-third of them attain hurricane intensity (reference 69). In any specific case, a storm's intensity can be quickly estimated by using the charts in references 51 and 67. Briefly, they form very rapidly in their source regions but in most instances they begin to dissipate and shear off within a few days so that they characteristically have a relatively short life. The principle cause of their quick dissipation is the region of extremely strong vertical wind shear (and to a lesser extent cold surface waters) directly in the normal path to the northwest (reference 70). This region is illustrated in figure 10-5. When tropical storms reach this region with surface easterlies but strong westerlies aloft, the top of the storm with the mid and high clouds is essentially sheared off, leaving a weakened low-level circulation similar to that shown in figure 10-4(b). Until the weakening begins, however, tropical storms are easy to locate on satellite photos and are usually separated from the vast regions of low stratus by a clear band which conforms to the cyclonic and circular shape of the storm itself. Figure 10-6 shows such a clear band surrounding tropical storm Bernice on 14 July 1969. As was discussed previously under "Stratus and Fog" and "Active Fronts" and shown in figures 4-14 and 8-1, the clear band can be explained alternatively by either rising motion or subsidence but for tropical storms, the latter is the most likely choice.



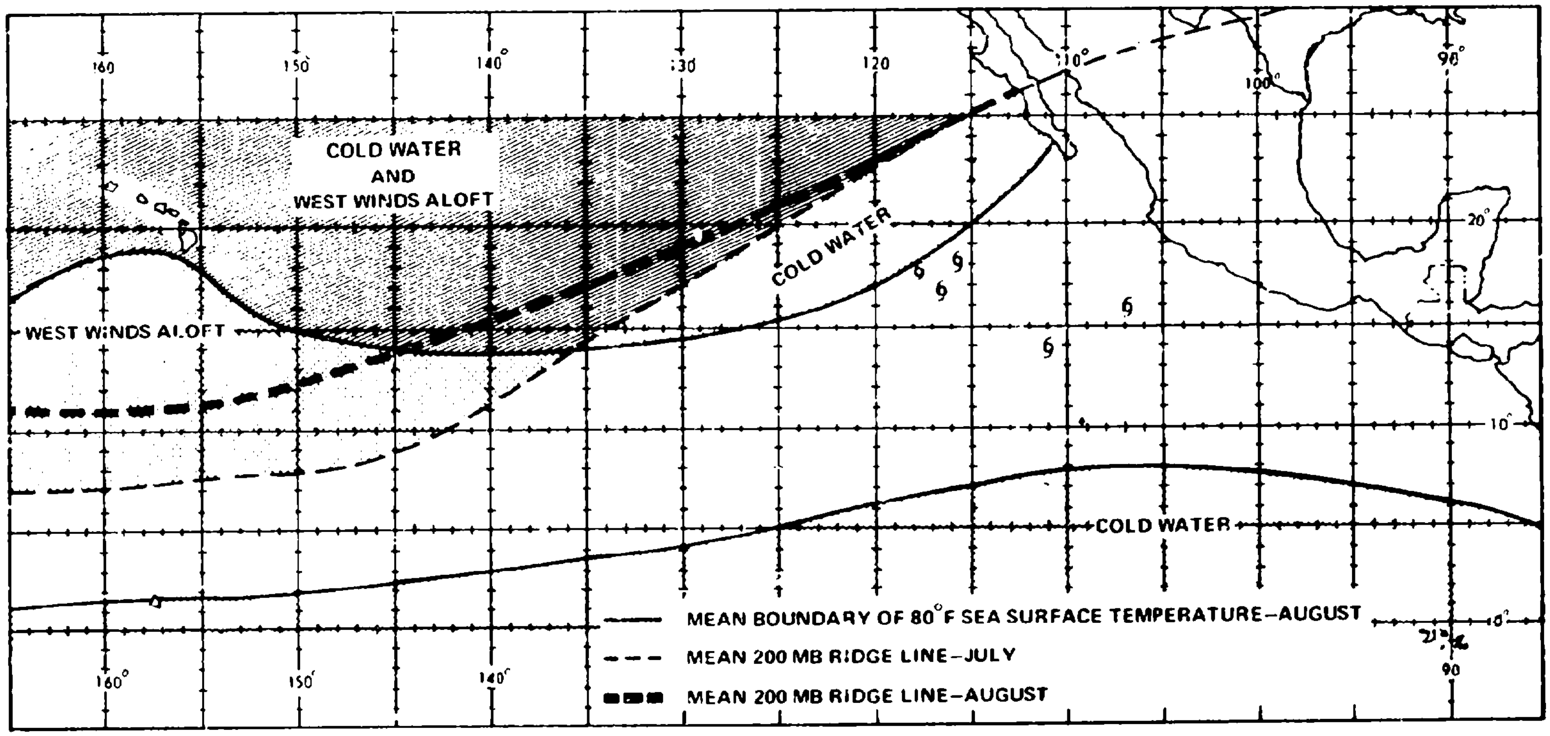
ESSA 4 APT of 6 September 1967.

From [illegible] Life Cycle of Hurricane [illegible]



APT of 12 September 1967, Showing Remains of Hurricane Lily Off California Coast.

Figure 10-4(b). Life Cycle of Hurricane Lily.



(Because of restrictions imposed by the limits of printing facilities, some of the smaller details had to be omitted in this copy of original figure.)

Figure 10-5. Schematic Depicting Position of Mean 200-mb Ridge Line for July and August and Mean 80°F Sea Surface Temperature for August. (From Sadler, reference 70.)

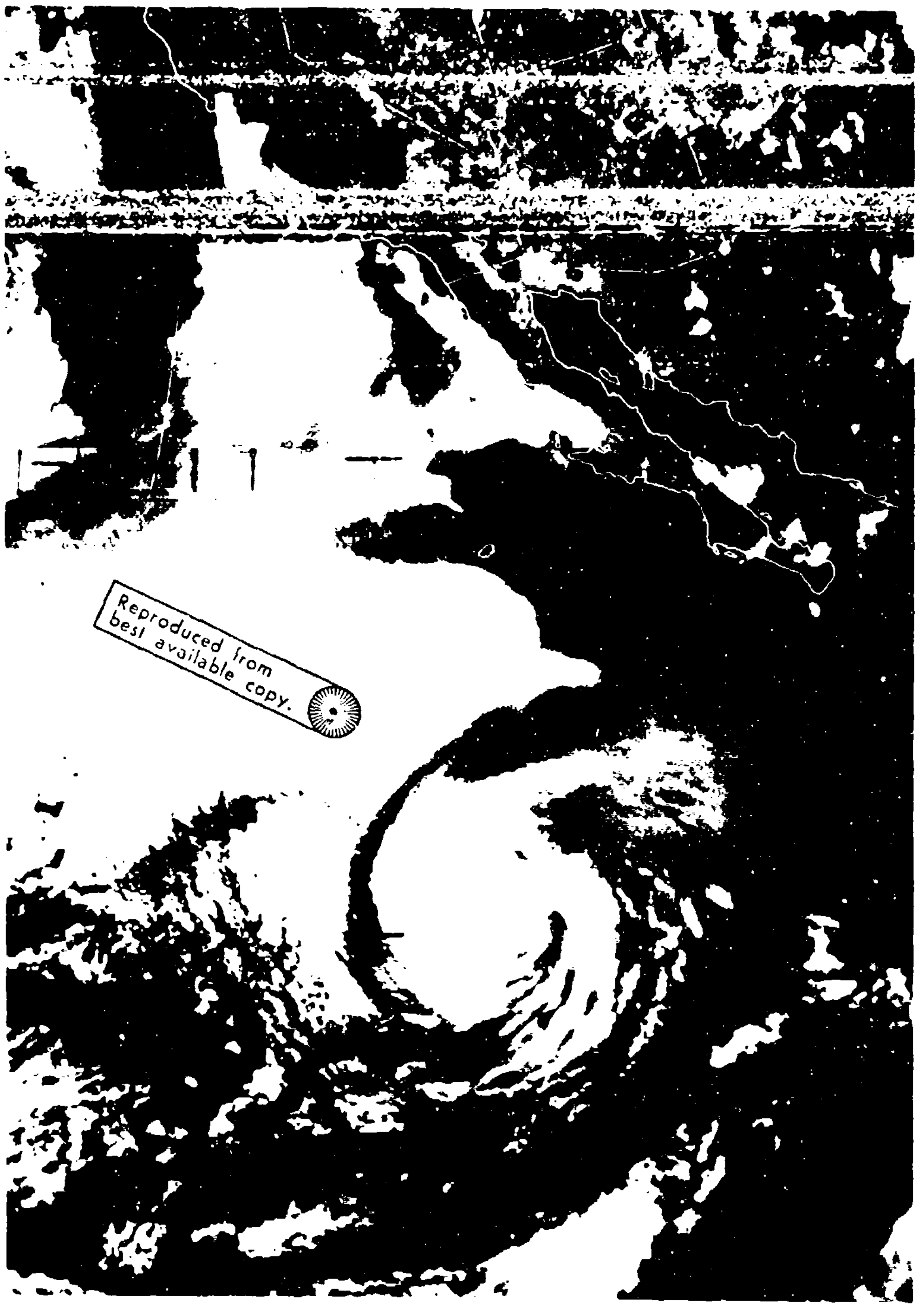


Figure 10-6 Clear Band Around Tropical Storm Bernice by ESSA 8 APT, 1716Z, 14 July 1969. Tropical Storm Bernice has been downgraded from a hurricane. A frequently observed clear band separates the storm's clouds from the stratus-covered area in its path.

Effects on Point Mugu Weather

Since heavy rains and high winds from tropical storms are extremely rare in southern California, it appears that the most important effect at Point Mugu from these storms is the occurrence of high southerly sea swells generated in the storm area. Large storm-generated swells may, if coupled with high tides, erode beaches and endanger beach buildings and instrumentation sites. The occurrence of such swells is discussed in appendix B.

As for atmospheric properties during periods of tropical air influx to coastal southern California, Point Mugu can expect periods of midclouds during which sprinkles and thundershowers are possible, particularly if upper winds are from the south or southeast. Warm temperatures, a lessening of typical stratus, and high humidities are also common.

PART IV. SPECIAL PHENOMENA WHICH MAY SEVERELY AFFECT RANGE OPERATIONS

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CHAPTER 11

REFRACTION DEFINED

Refraction is the bending of a ray of sound or electromagnatic energy, such as light or radar pulses, by a change in density of the medium through which it travels. There are many common examples of refractive effects in everyday life such as the shimmering on a sun-heated highway and the apparent change in shape and position of an object or person submerged in a swimming pool. At Point Mugu, where radar-tracking is such an important and integral part of range operations, the bending of the radar wave as it travels through the atmosphere is of prime concern.

REFRACTION MEASURED

Refractive effects are estimated by considering how the refractive index (evaluated in terms of "N"-units) varies in the vertical. In most places in the world, particularly over continental interiors, the refractive index decreases with height in the lower atmosphere by a standard average of 12 N-units per thousand feet. This is due to the usual decrease of temperature, pressure, and humidity with height. In the Point Mugu and coastal southern California region, and in certain other coastal and oceanic regions around the world, the refractive index often decreases with height at much larger rates within stratified layers in the lower atmosphere, and causes anomalous bending of radar waves (reference 5). Generally speaking, the greater the rate of decrease of N-units with height, the greater the amount of bending experienced by a radar beam (references 71, 72, and 73).

Since refractive corrections must be applied to all radar tracks to arrive at true target positions, atmospheric profiles of refractive index must be obtained. The Geophysics Division provides these profiles in two ways: (1) regular and slow-rise rawinsondes may be used to obtain data from which N-values are computed, or (2) a refractometer is mounted in an aircraft to measure N-values.

The rawinsondes measure temperature, pressure, and humidity with height; then N-values are computed from these data. The usual computer-reduced rawinsonde outputs (an example is shown in table 11-1) list refractive N-units as a function of altitude along with the other, more conventional

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Table 11-1. Point Mugu Rawinsonde Data, 0155Z, 29 July 1970

RAWINSONDE DATA (WBS-1)
STATION. PT MUGU CALIFORNIA NTD
0155Z 29 JULY 1970

FOR OP. NO. 2938 8721
ASCENT NO. 000
SIGNIFICANT LEVELS

ALTITUDE FEET	ALTITUDE M	TEMP DEG C	DEW PT DEG C	RH PCT	PRESS MBS	I/R N	NGRD N/FT	DIR DEG	SPD M/S	SPD KTS
12	4	17.8	13.6	77	1011.4	338	0	280	6	12
582	178	15.0	13.0	88	991.0	334	.007	287	4	8
1182	360	17.6	12.9	74	970.0	324	.017	293	2	4
1269	387	19.2	-7.5	16	967.0	272	.598	293	2	4
1712	522	23.6	-4.6	15	952.0	267	.011	292	1	3
2198	670	25.2	-5.2	13	936.0	261	.012	260	1	2
5463	1665	19.0	-1.2	25	834.5	246	.005	187	5	9
7271	2216	17.2	5.7	47	782.4	250	-0.002	188	7	13
9578	2919	11.7	5.9	68	720.0	239	.005	186	10	19
10133	3089	10.6	4.7	67	705.6	232	.013	183	10	20
11172	3405	7.9	4.9	81	679.2	228	.004	183	10	20
14408	4392	1.8	-0.7	84	602.0	198	.009	196	13	26
14995	4570	.6	-8.7	49	588.8	183	.026	194	13	26
15391	4691	0	-7.8	56	580.0	182	.003	193	13	26
17052	5197	-4.3	-5.0	95	544.3	179	.002	195	13	25
17835	5436	-7.0	-7.5	96	528.0	172	.009	203	13	25
18323	5585	-8.7	-9.3	95	518.0	168	.008	209	14	27
18520	5645	-10.2	-29.3	19	514.0	155	.066	211	14	27
19118	5827	-8.7	-30.7	15	502.0	150	.008	214	14	27
20364	6207	-8.7	-30.7	15	478.0	143	.006	217	13	25
21556	6570	-10.4	-32.1	15	456.0	137	.005	226	14	27
22003	6706	-11.4	-32.8	15	448.0	135	.004	227	15	28
23733	7234	-15.7	-36.2	15	418.0	128	.004	227	19	36
24515	7472	-15.6	-36.1	15	405.0	124	.005	229	19	37
29266	8920	-25.7	-44.2	16	333.0	105	.004	236	25	49
30882	9413	-27.8	-45.9	16	311.0	99	.004	236	26	51
35553	10837	-37.3	-54.3	15	254.0	84	.003	231	31	60
45317	13813	-56.6	0	0	162.0	58	.003	225	21	40
49510	15090	-63.7	0	0	132.0	49	.002	229	20	39

Table 11-1. (Concluded)

ALTITUDE FEET	ALTITUDE M	TEMP DEG C	DEW PT DEG C	RH PCT	PRESS MBS	I'R N	NGRD N/FT	DIR DEG	SPD M.S	SPD KTS
51509	15700	-64.7	0	0	119.5	44	.003	229	19	36
54219	16526	-61.4	0	0	104.5	38	.002	236	11	22
58994	17981	-59.2	0	0	82.7	30	.002	169	7	13
59854	18244	-60.0	0	0	79.3	29	.001	152	4	9
71636	21835	-51.6	0	0	45.1	16	.001	94	11	21
82448	25130	-49.3	0	0	27.2	9	.001	87	16	31
84901	25878	-44.9	0	0	24.3	8	.000	82	20	38
86980	26512	-45.6	0	0	22.1	8	0	87	17	32
88737	27047	-43.1	0	0	20.4	7	.001	64	15	29
89620	27316	-44.3	0	0	19.6	7	0	75	19	37
96768	29495	-40.6	0	0	14.2	5	.000	101	18	34
106975	32606	-40.2	0	0	9.0	3	.000	95	23	44
107990	32915	-41.2	0	0	8.6	3	0	98	24	46
108518	33076	-39.0	0	0	8.4	3	0	92	24	46
110191	33586	-37.7	0	0	7.8	3	0	89	29	56
114647	34944	-40.3	0	0	6.4	2	.000	77	32	63
115360	35162	-38.6	0	0	6.2	2	0	102	29	56

parameters. For convenience of computation, tables are available to Weather Center forecasters that give N-values as a function of temperature, pressure, and relative humidity.

When detailed profile data are needed for regions generally inaccessible to rawinsondes, the aircraft-mounted refractometer is used. This device measures N-values directly as air streams into the instrument while the aircraft flies up and down through the various layers. Whichever method is used, the refractive data may be plotted on charts either manually or by computer (figure 11-1) to show how the refractive index varies in the lower atmosphere as compared with the so-called standard rate of 12 N-units per thousand feet. These and other products help the data correction experts arrive at what they believe is a realistic picture of the positions and tracks of targets by providing them with the means to correct for refractive bending.

STRONG SUPER-REFRACTIVE LAYERS

Layers with large vertical N-gradients are common to the Point Mugu and Sea Test Range areas (reference 74). In fact, very strong super-refractive layers are so common to the local area that this condition could more properly be considered "standard" for PMR. During the months May through September, a strong super-refractive layer prevails just above the stratus clouds at altitudes roughly between 1,000 and 2,000 feet. This coincides fairly well with the average heights of the inversion during the stratus season. This is not a coincidence, for it is the combination of the decrease in humidity above the marine layer and the increase in temperature within the inversion which, together, result in a sharp decrease of N with height. Even without a temperature inversion, a sharp vertical decrease in humidity alone may result in strong super-refractive conditions. In general, inversions are present, however. Thus both strong super-refractive layers and the inversion are a result of strong, persistent subsidence from the Pacific High (references 4 and 5), and forecasting refractive conditions in the local area becomes largely a problem of forecasting the height and intensity of the subsidence inversion.

During the stratus season, the inversion when averaged over the whole day and at one place, shows only minor variations in height and intensity (see figure 4-10). Refractive conditions also are much the same from day to day, exhibiting a strong stratified layer within which there is a decrease in N with height similar to that shown in figure 11-1. Occasionally, there are also subrefractive layers (where N increases with height) near the surface and also at altitudes of 5,000 to 15,000 feet corresponding to regions of influx of tropical moisture. Even though refractive layers (and the inversion) may appear at nearly the same heights at the same time of day, day after day, there are nevertheless important variations in height and thickness within the day as well as with horizontal distance from Point Mugu. These diurnal and spatial variations may amount to hundreds of feet, far exceeding any variations attributable to synoptic disturbances during the summer months. They correspond to the pumping up and down of the marine layer in response to the land-sea-breeze regime and all the other topographically and heat-induced irregularities in the marine layer flow as discussed earlier under "Factors Modifying Stratus and Fog" (reference 19). Figure 11-2 shows the magnitude of the spatial variations of refractive index (N-units) that can actually occur. This example should probably be considered typical for the stratus season months. On a still smaller scale, there are other refractive and turbulent irregularities within the lower atmosphere which are detectable by special radar techniques (reference 76) and which may profoundly affect standard radars, but the importance of such anomalies and their precise cause is still not yet understood. These may be responsible for "unexplained" fading and may be accounted for only by statistical methods.

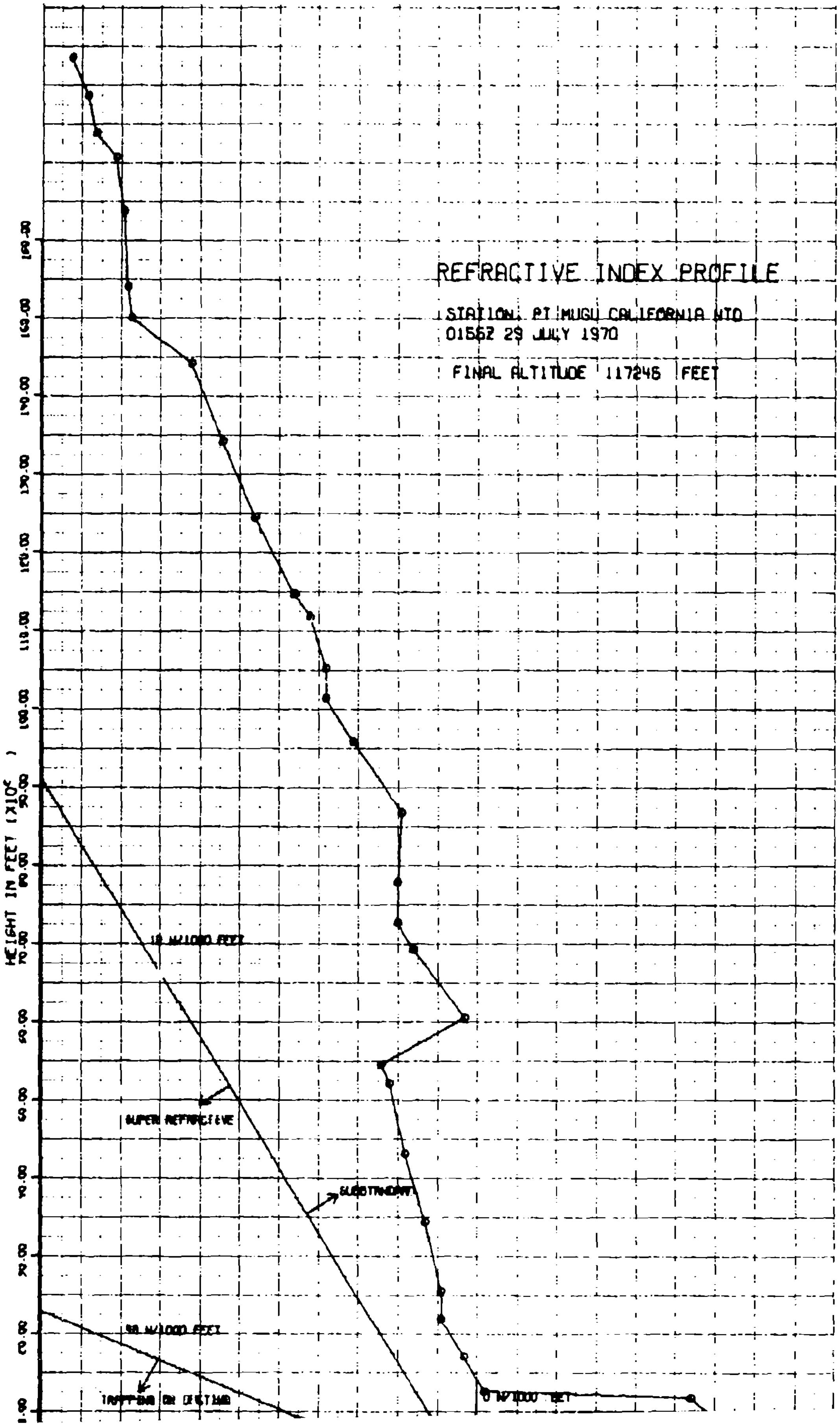

Figure 11-1 Computer Plot of Refractive Index (N-Units) From Point Mugu Rawinsonde; 01552

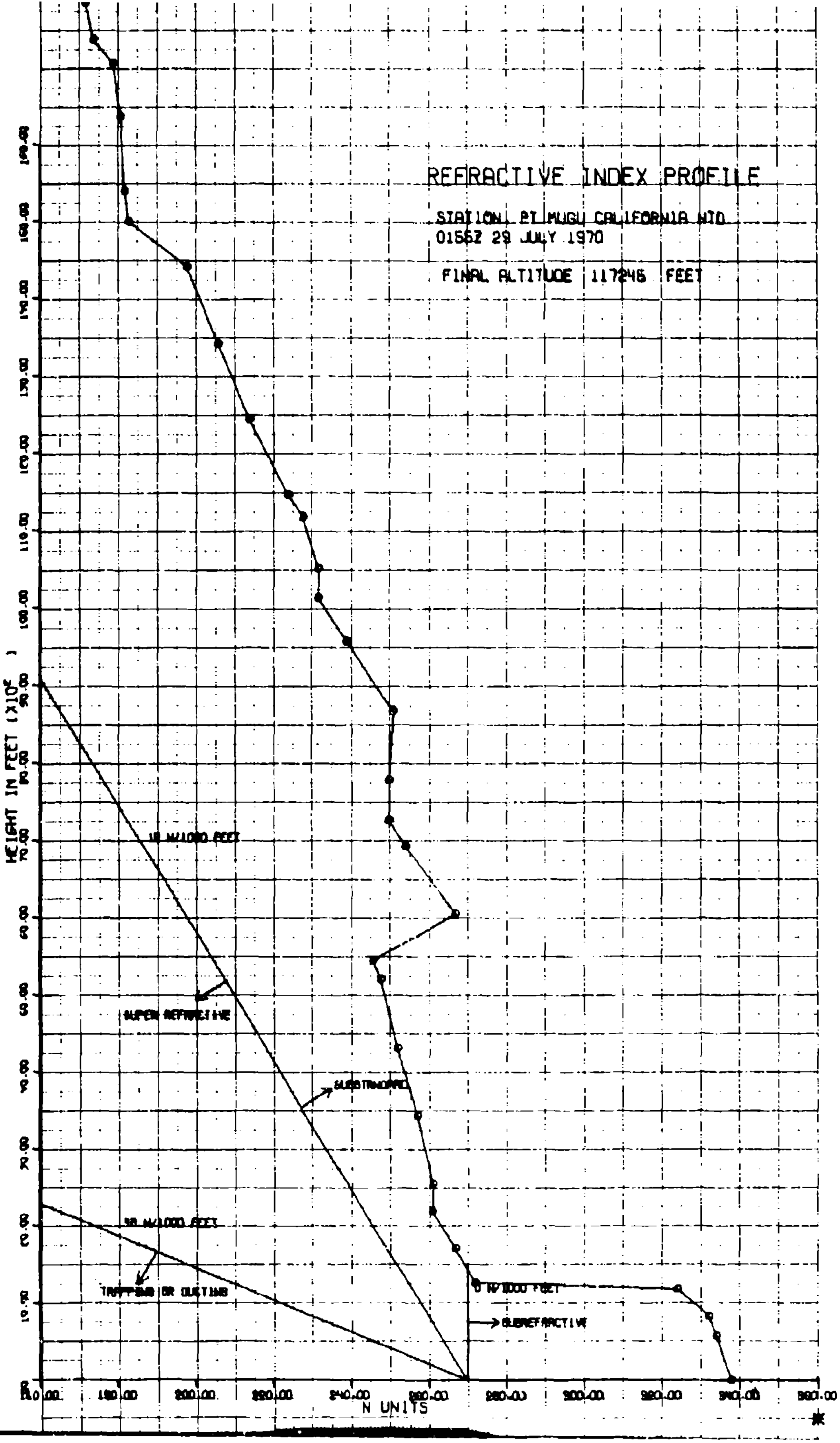

Figure 11-1. Computer Plot of Refractive Index (N-Units) From Point Mugu Rawinsonde, 0155Z, 29 July 1970.

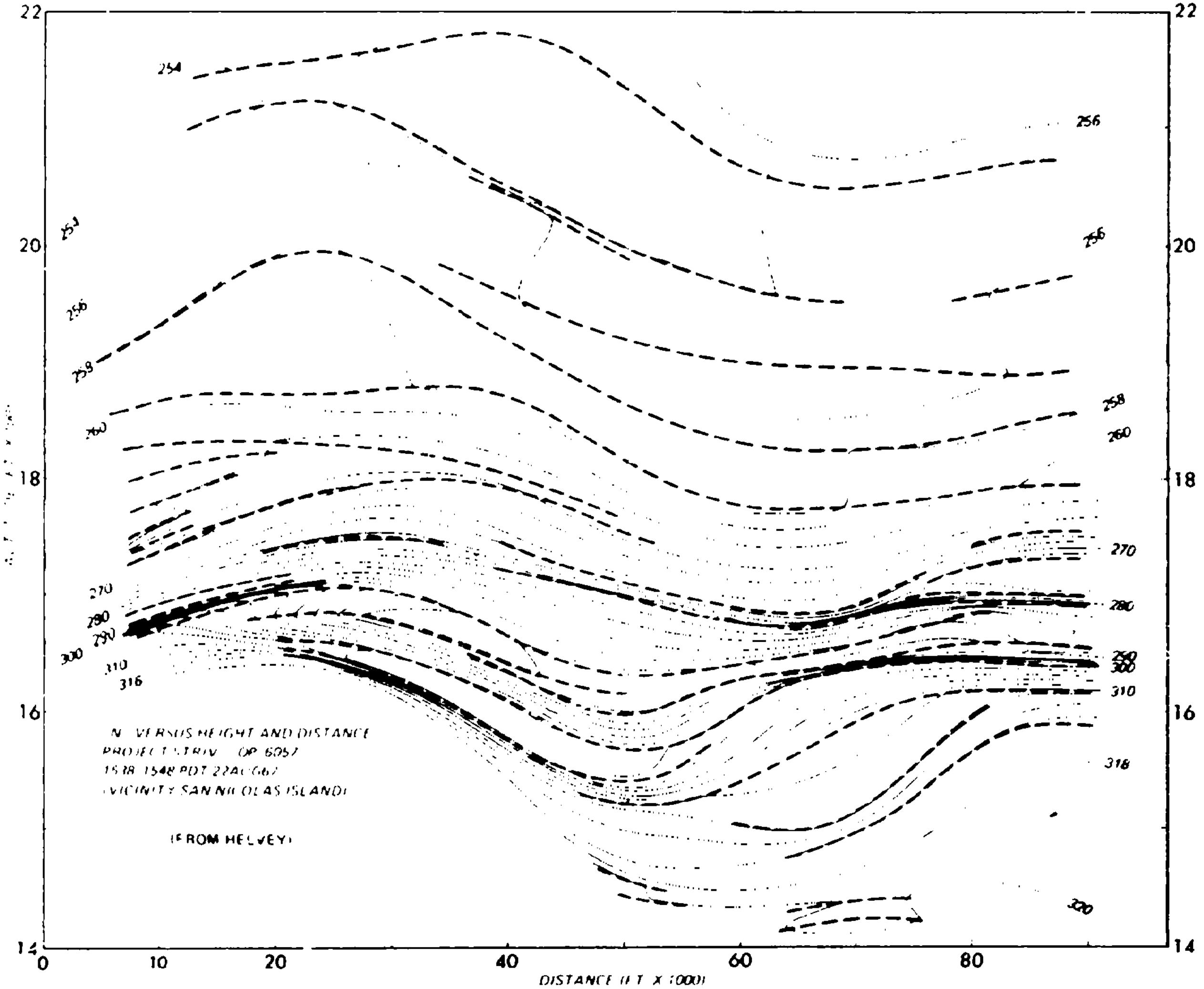

Figure 11-2. Cross Section of Refractive Index (N-Units) for 22 August 1967 in Vicinity of San Nicolas Island (From Helvey for Project STRIV.)

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During the cooler, nonstratus season months, the mesoscale and microscale variations generally are of secondary importance to the synoptic scale events. Strong super-refractive layers are still common, but they are much more sporadic, more likely to occur without a temperature inversion, and much more likely to change abruptly from day to day than during the stratus season months.

Operationally, any super-refractive layer with N-gradient of about 35 N-units per 1,000 feet can cause serious bending problems, and trapping conditions (discussed in a following section) are possible when the gradients reach 48 N-units per 1,000 feet or more. For planning purposes, it may be assumed that such strong layers are present in the lower atmosphere at PMR, probably 90% or more during the warm half of the year and probably 70% or more during the rest of the year, although actual numbers are not available for all intensity classifications of the layers. Actual statistics are available from San Nicolas Island sounding data. These data (summarized in reference 75) show a tendency for several layers at differing elevations to occur simultaneously. Some of this effect may be due to the direct influence of the island itself. It is probable that even over the open waters of the Sea Test Range, multiple layers, particularly during the more complex winter season, do occur. It is also probable that strong super-refractive layers (particularly the very strong ones) are more common over the Sea Test Range than they are over Point Mugu and land radars.

TRAPPING CONDITIONS AND RADAR HOLES

Estimates of present and future refractive conditions in the atmosphere are essential to evaluating radar coverage. So-called standard refraction (decrease of 12 N-units per 1,000 feet) results in a gentle bending of radar waves equivalent to the curvature of a circle having a radius about four-thirds that of the earth. Super-refractive conditions (rate greater than 12 N-units per 1,000 feet) cause more severe bending. If the rate of decrease of N equals or exceeds 48 N-units per 1,000 feet, bending may be so severe that "trapping" or confinement of energy may occur within the layer. When this happens, energy does not penetrate through the layer, and a "radar hole" or blank region may occur just above it. Targets within the *trapping* layer could be detected by radar at relatively great distances although targets in the radar hole might escape all but visual detection.

Locally, super-refractive layers with intensities several times that required for trapping are frequently experienced. Fortunately however, trapping and radar holes generally appear only for radar energy with elevation or incidence angles with respect to a super-refractive layer of less than 3 degrees. Thus, even with extremely strong refractive layers present, radar energy passing through at relatively high angles (greater than 3 degrees) will be largely unaffected in terms of radar holes and trapping. Radar energy incident to refractive layers at very large angles will undergo little more than "standard" bending. Air-

borne radars, by their very mobility, permit the radar operator to avoid trapping conditions and to reduce the size of a radar hole by varying the height of a radar so that the elevation angle with respect to a strong refractive layer is large. Fixed radars, such as those over land, are often subject to the whims of the atmosphere including fading and loss of track when operated at low angles. Thus for a given atmosphere, various targets may or may not be radar-visible. Figures 11-3(a) and (b) show raytraces (schematic views) of radar energy from radar sites at the surface and at 1,000 feet passing through an actual and typical summertime refractive layer as shown in figure 11-3(c). The super-refractive layer is strong enough to cause trapping but the energy coming from the 1,000-foot radar site is much more affected by the atmosphere than is energy from the surface site because the former is striking the strong layer at very small elevation angles. Note the differences in the patterns of rays.

FORECASTING REFRACTIVE LAYERS

The problem of forecasting refractive layers is probably as difficult as any of the other forecasting problems experienced at a west coast station. During the warmer stratus season months, prediction must be based largely on correctly interpreting the effects of weak troughs and ridges aloft as well as applying available knowledge on some of the more systematic mesoscale and diurnal variations discussed under "Factors That Modify Stratus and Fog" (chapter 4). During the rest of the year, refractive variations caused by large-scale synoptic changes are much more amenable to forecasting. When a strong ridge forms or moves over the coast, subsidence is usually quite pronounced and the inversion and accompanying super-refractive layers may be expected to be quite strong and low. The most pronounced super-refractive layers often occur immediately preceding and following Santa Anas at Point Mugu. Santa Ana winds usually destroy any layers already present; while over water extreme super-refractive conditions may prevail just above the surface where the hot, dry winds overlie a shallow moist marine layer. When troughs move into the local area, subsidence is weakest, and the inversion and associated strong super-refractive layers usually lift and weaken. In winter when troughs are especially active, the inversion and super-refractive layers are sometimes destroyed altogether for a few days.

Generally, exact heights and intensities of refractive layers are almost impossible to forecast, but trends of height and intensity may be closely estimated several days in advance by careful examination of the progression and development of ridges and troughs aloft and by the forecaster having a good knowledge of seasonal factors such as summertime persistence.

FIGURE 11-3 (a)

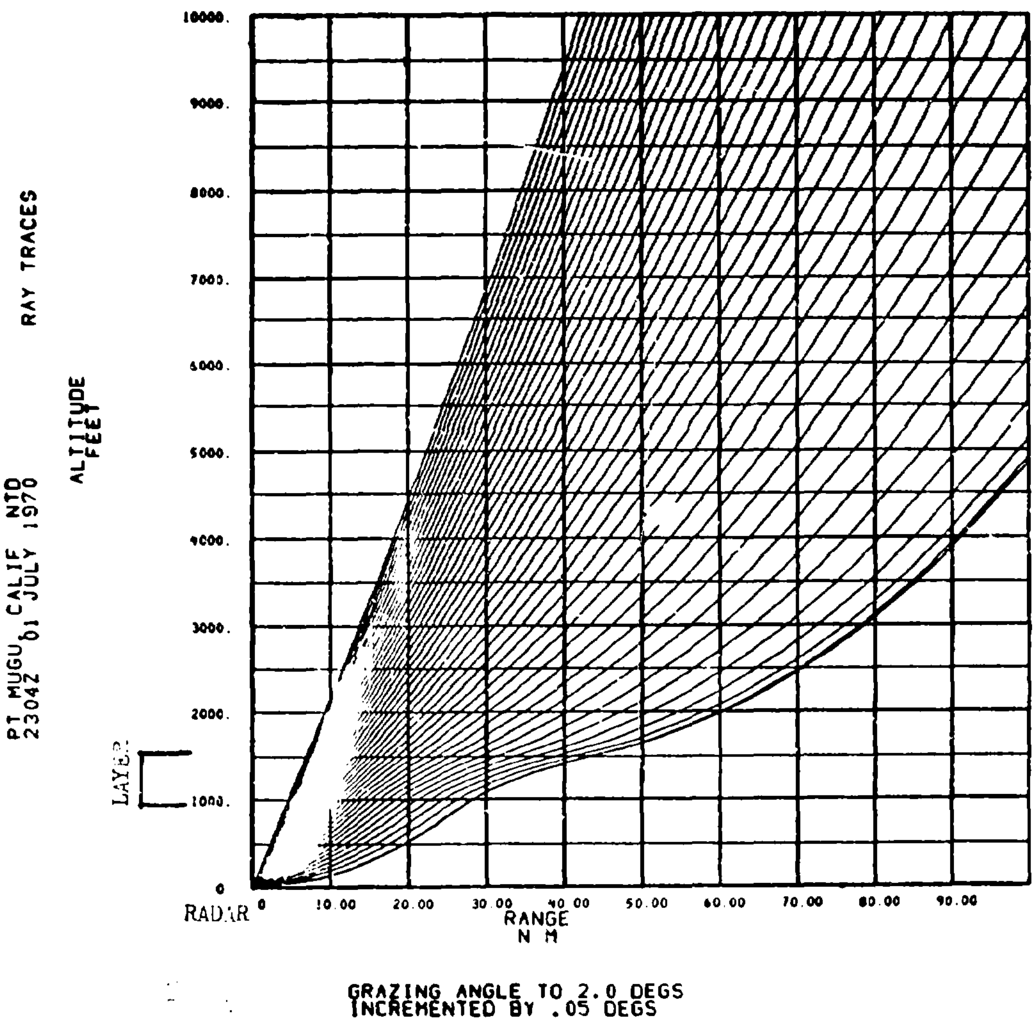

Figure 11-3(a). Sample Raytrace for Point Mugu Surface Radar at 2304Z, 1 July 1970.

FIGURE 11-3 (b)

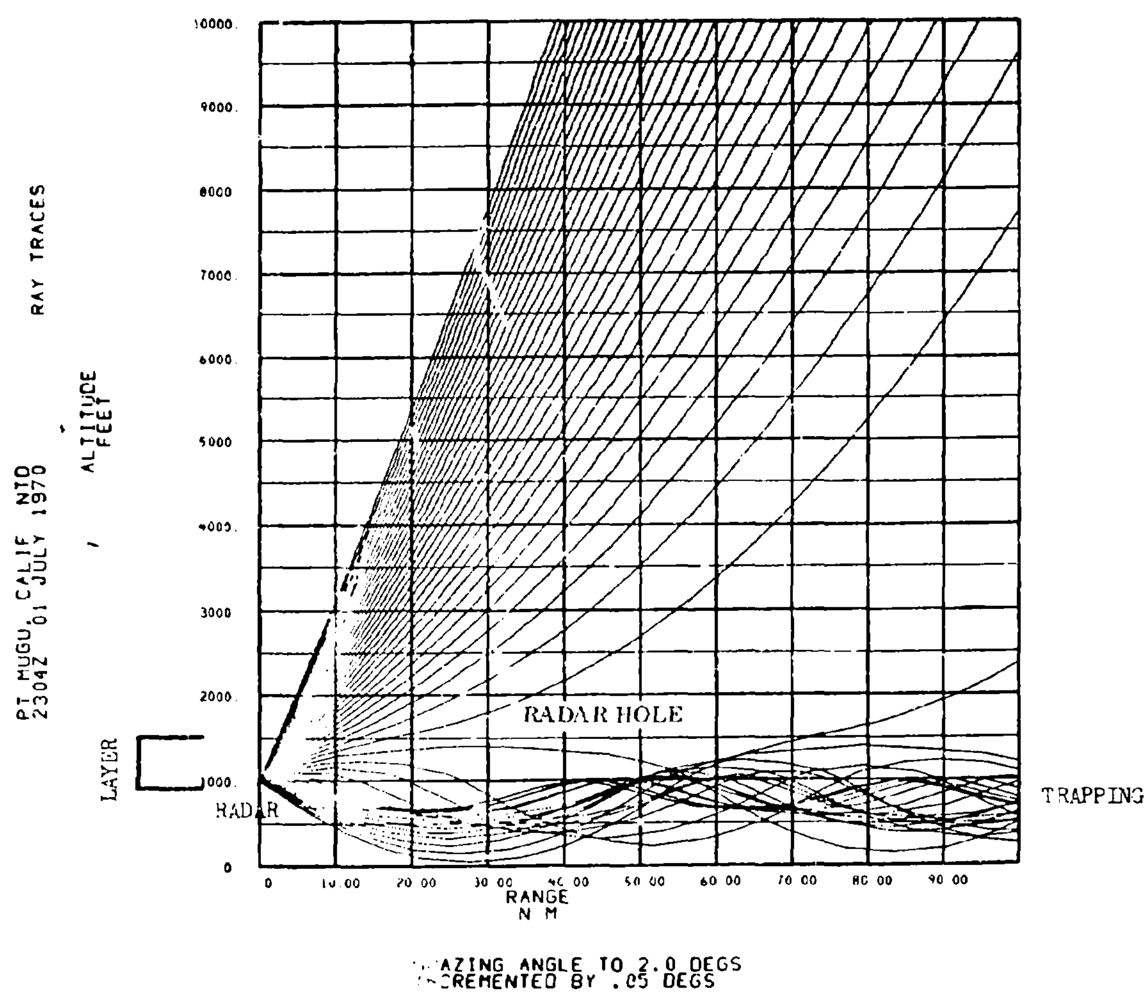

Figure 11-3(b). Sample Raytrace for Radar at 1,000 Feet MSL at 2304Z, 1 July 1970.

FIGURE 11-3 (c)

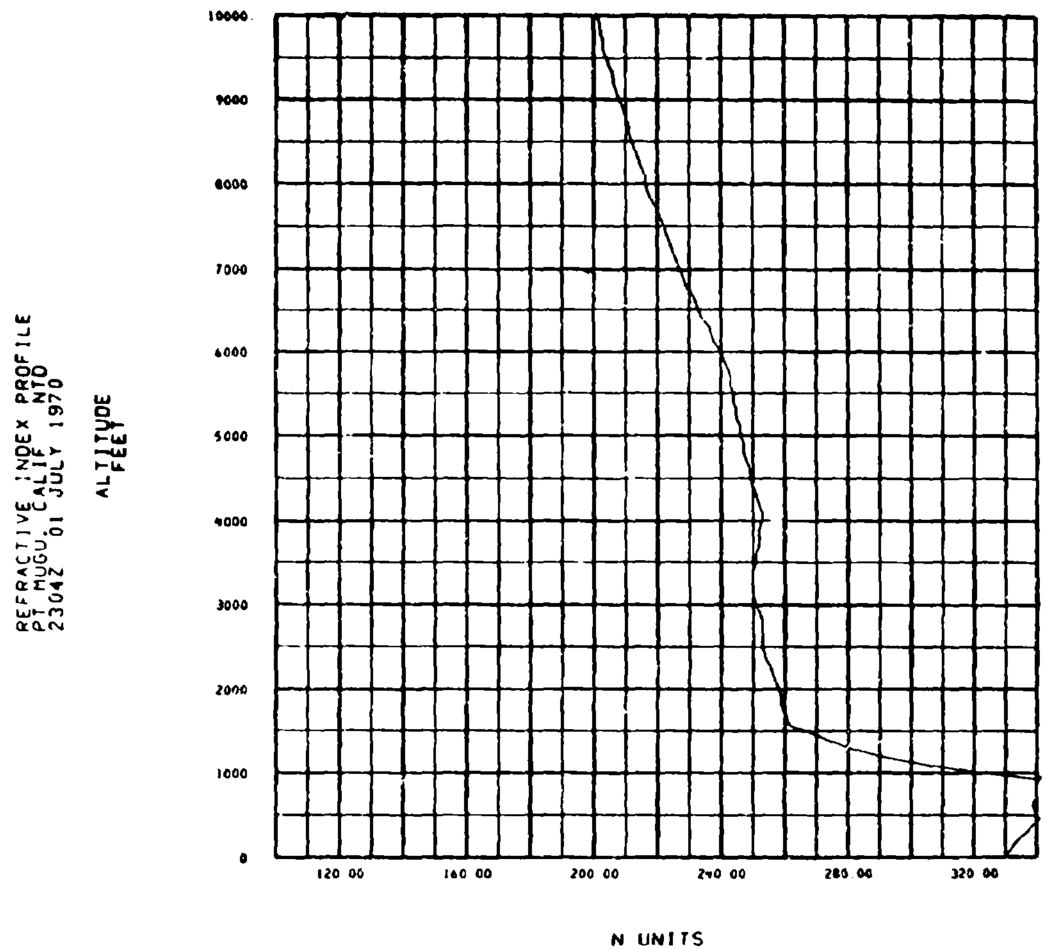

Figure 11-3(c). Refractive Index (N-Units) Profile for Point Mugu at 2304Z, 1 July 1970.

THUMB RULES FOR PREDICTING REFRACTIVE CONDITIONS AT POINT MUGU--SEA TEST RANGE AREAS

The following aids and guides should be used by the forecaster when estimating the trends of refractive conditions in the Point Mugu area. Many of them are based on material presented in reference 75.

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Strong superrefractive layers (gradients > 15 N per 1,000 feet) and potential trapping layers (gradients > 48 N per 1,000 feet) generally coincide with an inversion layer	√			11-8
Strong superrefractive layers are frequently found just above a status deck.	√			11-8
Strong refractive layers and potential trapping conditions are most persistent in summer but occur with great frequency all year.	√			11-8, 12
In summer, such layers are present up to 60% of the time over the Sea Test Range.	√			11-12
At San Nicolas Island, potential trapping layers are most frequently found at or near surface (571 feet MSL) (reference 75)	√			*
A secondary maximum of potential trapping layers at San Nicolas Island (and possibly the primary maximum at Point Mugu) occurs between elevations of 400 and 600 meters (1,300 and 2,000 feet) in mid-summer (reference 75)	√			*
The thickness of potential trapping layers at San Nicolas Island is most frequently 50 to 99 meters (164 to 325 feet) (reference 75).	√			*
The thickness of potential trapping layers over Point Mugu is probably greater than over the Sea Test Range, but the intensity is probably somewhat less.		√		11-12
Pronounced time and space variations of refractive layers, and large differences between upwind and downwind (lee) sides of islands in the Sea Test Range area are common in coastal southern California. Such mesoscale variations are more important than synoptic variations much of the time during summer	√			11-8, 11
In addition to the usual strong, low-level super-refractive layer, a subrefractive layer is sometimes found in summer between 5,000 and 15,000 feet because of influxes of tropical moisture from the southeast.	√			11-8
Ridging over the west coast increases the likelihood of strong refractive layers, and lowers and intensifies them	√			11-13
The likelihood of trapping conditions for surface radars at Point Mugu is greatest just before and just after Santa Anas	√			11-13

*See reference 75

THUMB RULES FOR PREDICTING REFRACTIVE CONDITIONS AT POINT MUGU--SEA TEST RANGE AREAS (Concluded)

	Confidence Factors			Page
	Likely	Frequently Plausible	Speculative	
Santa Ana winds [illegible] destroy refractive layers when the winds extend down to the surface but extreme superrefractive conditions prevail at sea where a shallow marine layer underlies the hot dry winds. Thus, when Point Mugu has a Santa Ana, trapping conditions are very likely over the Sea Test Range.	✓			11-13
Movement or development of a trough aloft off the west coast results in weakening and lifting of refractive layers and, in winter, may totally destroy them.	✓			11-13
Catalina Eddies produce an increase in height of refractive layers at Point Mugu.	✓			**
Radar energy will be trapped within sufficiently strong superrefractive layers only at the angles of incidence of less than 3 degrees with respect to the layer.	✓			11-12
There appear to be numerous small turbulent bubbles or anomalies within the marine layer which may be responsible for temporary fading of signals but which may also be randomly [illegible]		✓		11-8

**See Chapter [illegible]

CHAPTER 12. SMOG

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CHAPTER 12

SMOG DEFINED

The term "smog" was originally coined to describe a combination of smoke and fog in the atmosphere (reference 6). More recently, it has been applied to a mixture of pollutants from automobiles and industrial wastes and their reaction products that have accumulated in the atmosphere to the point of being noticeable visually, by instrument, or as a human irritant (reference 6). The term "smog" has been gaining worldwide acceptance over the last few years, but apparently the chemical nature of the mass of pollution differs from city to city. In southern California, smog is largely photochemical, that is, "cooked" by the prevalent sunshine into complex mixtures of ozone, nitrogen oxides, and hydrocarbons (reference 78) which cause eye irritation, smell oily, and look brownish (depending on sun angle and temperature), and along with other particulates, severely restricts visibility. The symptoms and characteristics of a large mass of smog seem to differ somewhat between coastal locations and inland sites as well as from day to day (weather change) and season to season (sunshine change). Various studies are currently probing into some of the relatively unknown aspects of southern California smog (reference 78a and 78b).

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IMPORTANCE TO POINT MUGU

The importance of smog to Point Mugu lies chiefly in the fact that one of its primary characteristics is reduction in visibility. Normally this reduction does not preclude the conduct of range operations but it frequently restricts visibility to 3 miles or less, thereby resulting in IFR (instrument flight rules) flying conditions. When visibilities reach these very low values, the terms smog, fog, and "marine haze" are sometimes confused, especially since they occur under the same general conditions in which marine air is capped by an inversion.

According to both Circular "N" (reference 79) and the new manual on surface observations (reference 80), visibility restrictions must be attributed to fog if the temperature-dewpoint spread is 4°F or less or when the relative humidity is very high. When the spread is greater than 4°, the restriction should probably be attributed to some other condition. In these cases, haze and smoke (HK) or just haze (H) are usually cited. This gives rise to the often cited possibility that oceanic "marine haze" or some other natural condition is really causing the visibility restriction, particularly when the air is damp and there is no noticeable eye irritation or high oxidant values observed near the coast. "Marine haze" does not seem to be acceptable as the cause, however, since

the thick coastal haze often smells like smog, leaves a dirty, greasy residue on automobiles like smog, and often appears to move into the local area directly or indirectly from the smoggy Los Angeles area.

So far, subjective observations indicate that marine air along coastal locations in California remote from Los Angeles and other large urban areas do not markedly restrict visibility unless complete saturation or fog is actually occurring. This clean marine air is often transparent to 10 or 15 miles below a stratus deck, whereas locally, it is often impossible to determine exactly where the base of stratus is. Clean or transparent marine air at Point Mugu seems to occur only following a fresh impulse of polar air and frontal passage locally, or a shift to a more persistent westerly wind. On numerous occasions following such events, Point Mugu observations have revealed unrestricted visibilities with very low, sharply defined stratus and relative humidities of about 100%.

It appears then that the coastal hazy conditions at Point Mugu are not due so much to any natural origin as they are to pollution in a moist atmosphere. Further supporting evidence for this idea comes from a recent study at San Nicolas Island (reference 78b) which shows a significant amount of man-made pollutants, aerosols, and byproducts in the lower marine atmosphere. Other recent studies at FWC Alameda (reference 81) and FWF San Diego (reference 82) show a maximum frequency of offshore hazy conditions and low or mediocre visibilities greatly concentrated off the coast from the Los Angeles Basin. Thus there is now substantial evidence that much of "marine haze" of a purely natural origin is a myth. The problem of correct observation of low visibility might be alleviated if synoptic reporting codes of low visibility included a special designator for reporting visibility restriction due to pollution or smog, based on a relatively objective set of guidelines for its use and interpretation.

The problem of identifying a visibility restriction as fog or smog is further compounded by the fact that both may occur simultaneously under saturated conditions, particularly at the coast, and that the smog itself may actually act as condensation nuclei and induce the occurrence of fog and stratus. Past studies (reference 7) have already shown that stratus occurs at lower relative humidities over Los Angeles than it does over more remote areas of coastal California, presumably a result of the numerous aerosols and particulates present with smog.

There are three smog-caused phenomena which are of extreme operational importance to PMR: the first is visibility restriction which can alone result in IFR field conditions and preclude some operations involving optical tracking; a second is the inducement of stratus and fog formation which results in further degradation of visibility and ceiling conditions and therefore aids further in producing IFR conditions; and the third is smog-caused delay in normal daytime evaporation or dissipation of stratus thereby extending the periods of IFR or unsatisfactory conditions.

HOW SMOG GETS TO POINT MUGU

Just as moisture is generally considered to be contained within the marine layer by the prevalent subsidence inversion, pollution is also thought to be mainly restricted to the turbulent layer beneath the stable layer of warm air*. In general, the lower and stronger the inversion, the greater the concentration of pollutants below it. However, very smoggy and polluted air may also occur when the inversion is high and relatively weak if the deeper marine layer is rather stagnant for prolonged periods and acts as a receptacle for all the fumes and pollutants put into it.

Characteristically, on an average day smoggy air masses slosh back and forth across the coastal basins of Los Angeles and the Oxnard Plain. During the day, the normal sea breeze blows the air inland where it accumulates large amounts of pollutants from the growing numbers of sources both locally (reference 83) and in the Los Angeles area. The inversion, other stable layers, and mountain barriers prevent a great deal of the pollution from escaping both vertically into the free atmosphere and horizontally into the desert. At night the land breeze drift returns part of the original polluted air to offshore areas from where it is again driven landward the following day and subjected to a fresh supply of smog ingredients. In this way, concentrations can build up over large areas during stagnant weather regimes subject to wind flow, inversion height and strength, and venting aloft of smog forced up the heated slopes of interior mountains.

The land breeze over Los Angeles frequently results in an early morning, offshore deposit of smog over the Santa Monica Bay. The initial sea breeze later each morning is frequently from the southeast as observed from surface hourly reports and buoy data (18.2 nmi due south of Point Mugu) and some of the offshore smog travels up the coast toward Point Mugu. The extent it travels depends upon the strength and persistence of the southeast wind and the amount of pollution. Smog "fronts" moving in from the southeast and south have been documented at Point Mugu on numerous occasions, both by analyses of visibility (reference 32) and by balloonborne measurements of ozone (reference 33). The latter show ozone maximums at Point Mugu within the inversion which are traceable to the Los Angeles Basin. These influxes of smoggy air are sometimes sudden and result in rapid decreases of visibility locally. The outer limits of the smoggy mass appear to extend many miles seaward but their advancing edges seem to be rather sharply defined as seen on visibility analyses (figure 12-1) and occasionally captured photographically as in figure 12-2. In the latter case, the smog bank remained just to the east and south of Point Mugu at the position shown in the photo, but on the following day, it moved in across the station with southeast

*Higher layers of smog within and above the inversion do occur, however, and current concepts of smog extent are being revised.

winds dropping the visibility from 15 miles at 1000 PST to 3 miles at 1100 PST. On those same two hourly reports, the relative humidity actually lowered from 59% to 55%, humidities which strongly imply the source of the hazy air to be pollution from Los Angeles rather than fog.

In predicting visibility at Point Mugu, it seems that hourly visibility analyses such as that shown in figure 12-1 would prove useful for short-term forecasts by showing the progression of low-visibility, smoggy air along the coast. Both visibility and wind data are routinely available from hourly reports on both SA 35 and SAUS 5 scans, and extrapolation of smog positions could give a qualitative estimate of the time of arrival of hazy air at Point Mugu (reference 32).

The occurrence of such well-defined smog boundaries are not limited to the Point Mugu area. They occur regularly throughout the Los Angeles area wherever the polluted marine air advances into a relatively unpolluted area. On most smoggy days, a sharp smog bank moves eastward through the Los Angeles Basin reaching Riverside, California in late afternoon (reference 84) while an arm of smog often stretches into the San Fernando Valley from the east, resulting in a wall of smog where the polluted air meets the westerly sea breeze from the Oxnard Plain. This latter feature has been named the San Fernando Convergence Zone (reference 85). Smog fronts at this convergence zone, near Riverside and in the Point Mugu-Oxnard Plain area, are all visible in figure 12-1.

The influx of smoggy air from Los Angeles into the Point Mugu area on a regular basis results in a "background level" of pollution which varies in severity according to local weather, wind, and inversion conditions. Superimposed on this background level is a growing and significant amount of locally-generated pollution from automobiles and from numerous stationary sources within the Oxnard Plain (reference 83). This additional smog is also subject to the daily sloshing back and forth by the land- sea-breeze circulation so that Point Mugu is subject to a complex source of polluted air and low visibilities. Low visibilities at Point Mugu in earlier years seemed to be associated with predominantly southerly winds (based on a study of September noon visibilities for the years 1949 through 1969 reference 34), but the same study shows that in more recent years even westerly winds are associated with low visibilities. This may be a direct result of the substantial increase in sources of pollution both locally and westward to Santa Barbara. There is also good evidence that pollution is now so widespread that local winds are a poor parameter to use in predicting smog without consideration of specific or general trajectories of the air for periods of many hours before the time in question. On at least some of the smoggy, low-visibility days at Point Mugu when local winds are

FIGURE 12-1

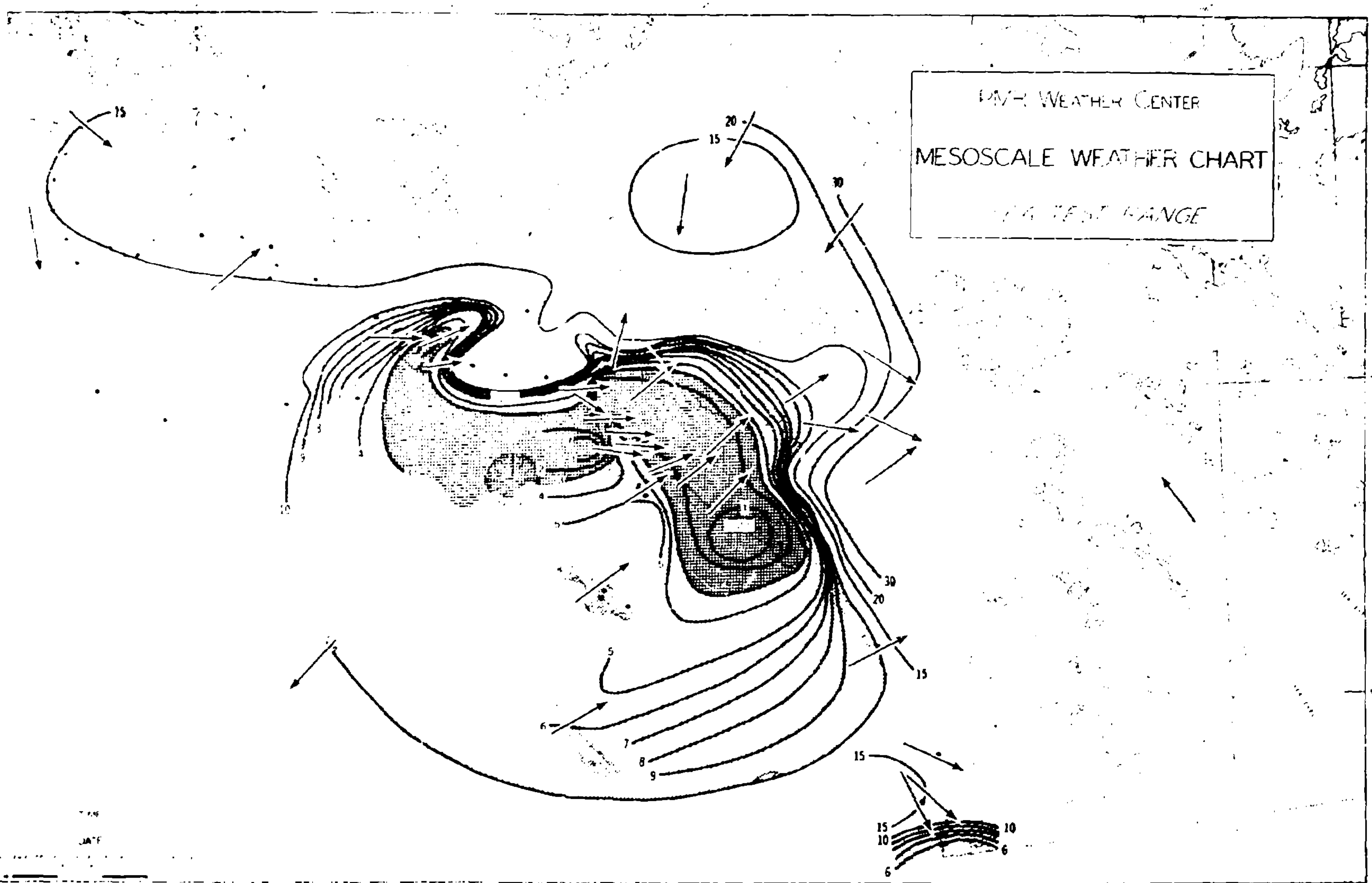

Figure 12-1 Analysis of Visibility Patterns Over Coastal Southern California for 1300 PST, 28 October 1965. (Reference 32.)

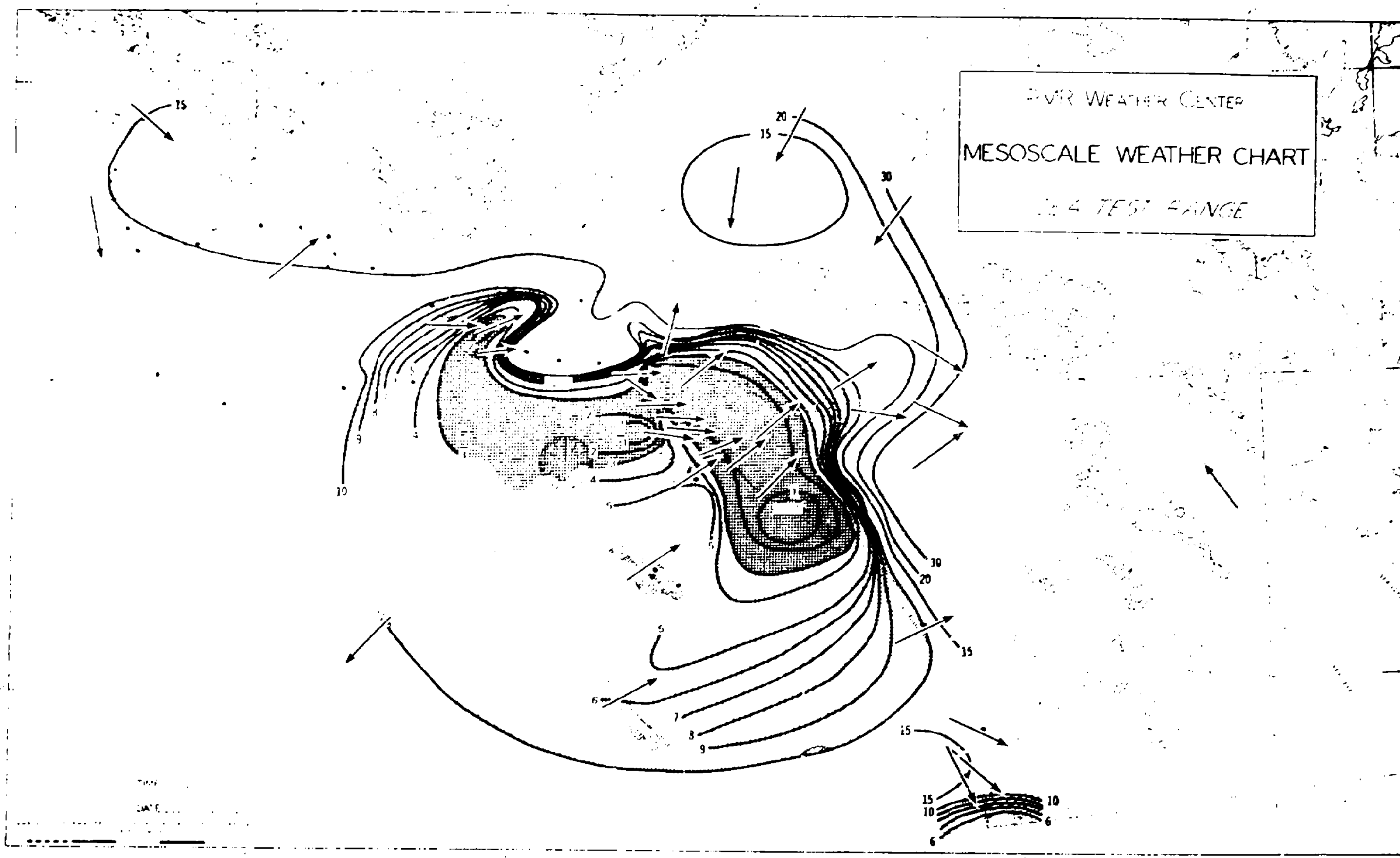

Figure 12-1. Analysis of Visibility Patterns Over Coastal Southern California for 1300 PST, 28 October 1965. (Reference 32.)

FIGURE 12-2

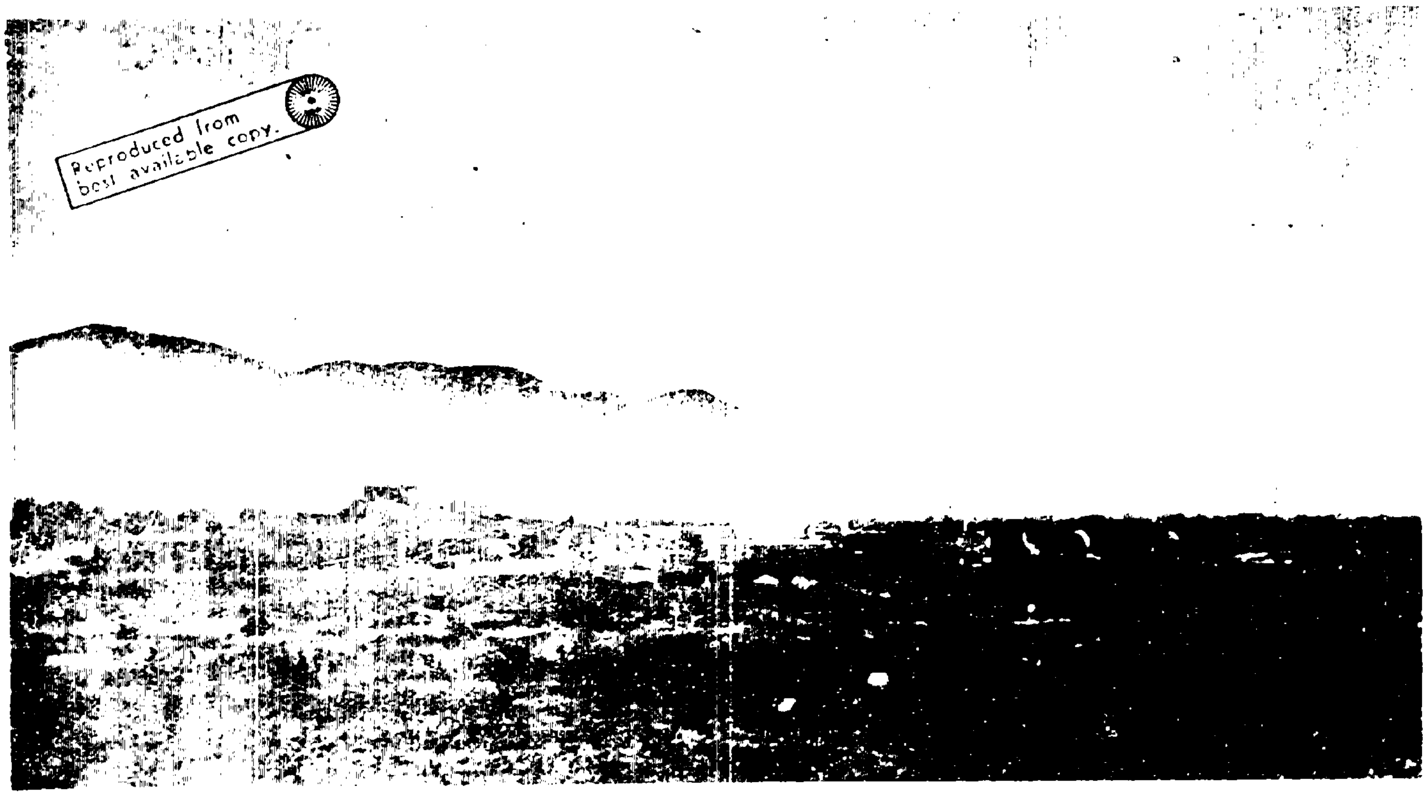

Figure 12-2. Smog Front to Southeast of Point Mugu at 1150 PST, 18 January 1971.

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from the west, winds observed on Laguna Peak (1,450 feet MSL) as recorded in the Weather Center were from the southeast, indicating that regardless of the surface wind direction, the general low-level flow originated from the Los Angeles Basin. Thus the westerly surface winds probably represent shallow sea-breeze circulations within an overall smoggy air mass. Current studies of 3 years (1968-1970) of available wind data from Laguna Peak show a good correlation of Point Mugu visibilities of 2 miles or less observed at midday (1100-1300), August through October, with east-southeast winds on Laguna Peak (figure 12-3). Those hours for these late summer months are generally considered to be fog-free and nearly coincide with the annual minimum of occurrence of overcast conditions at Point Mugu (see figure 4-5). Thus it appears that smog-caused very low visibility at Point Mugu is associated with east-southeast winds on Laguna Peak.

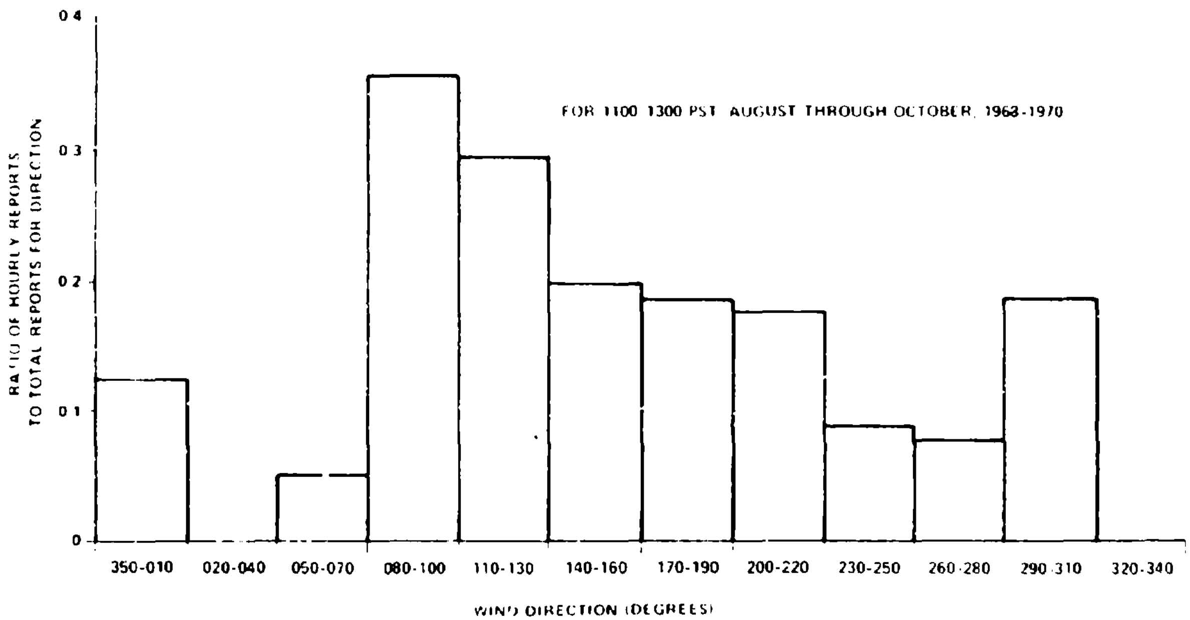

Figure 12-3. Normalized Frequency of Occurrence of Point Mugu Visibilities of Less Than 2 Miles as a Function of Laguna Peak Wind Direction.

The worst sieges of smog at Point Mugu appear to occur with low-level southeast flow preceding and following Santa Anas when the inversion is very low and strong. They also occur in the moderate to strong southeast winds preceding wintertime fronts and, in general, periods of stagnant marine air characterized by very weak winds (from any direction). In addition, Catalina Eddies appear to advect smog into the local area.

GUIDES TO THE OBSERVATION AND PREDICTION OF SMOG AT POINT MUGU

The cause of low visibilities at Point Mugu is often difficult to determine due to confusion of the terms fog, smog (or man-made pollution), and "marine haze" (certain oceanic natural aerosols such as sea salt particles). Parameters such as temperature, dewpoint, smell, color, wind, and synoptic weather situation must be studied and used as clues in identifying the source of the visibility restriction. If the temperature-dewpoint spread is 7°F or more, and the wind at Point Mugu (or more importantly, at Laguna Peak) has been from the s o u t h or southeast anytime within the past 3 hours, any visibility restrictions other than those due to precipitation and blowing dust should be attributed to smog and labeled "HK."

Smog may be present even when the temperature-dewpoint spread is less than 7°. On such days, nighttime cooling often results in rapid stratus formation and not infrequently, d e n s e fog. The presence of smog within the fog is detectable if the air appears dirty or smells oily or if smog was noted to exist before the onset of fog. The combination should be correctly designated on observations as "FHK," even during nighttime hours.

Smog is not always uniformly distributed over the Point Mugu area. At the onset of Santa Ana winds,

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low visibilities caused by smog may be present near Mugu rock and over the beaches while inland air is clear or even restricted in blowing dust if the northeasterlies are sufficiently strong. Frequently during warm periods, a thick blanket of smog will remain offshore or near Mugu Rock in the morning, waiting for the return of the sea b r e e z e before enveloping Point Mugu.

If the wind is blowing, or forecast to blow, from the southeast at Point Mugu or Laguna Peak (they are frequently different), and stations such as LAX, LGB, SMO, and HHR reported visibilities of 6 miles or less due to HK (smog) sometime during the past 24 hours, look for reduced visibility and smog locally.

When offshore flow over the Los Angeles Basin advects smog well off the coast or when generally stagnant conditions prevail over the Oxnard Plain, even southwest or west winds may transport smog into Point Mugu.

In general, southeast winds and smog frequently occur together during heat waves, before and after Santa Anas, ahead of active cold fronts, with Catalina Eddies, and when the nighttime land breeze veers to a daytime sea breeze. The smog under these conditions can be expected to reduce visibilities and cause more stratus and fog as well.

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CHAPTER 13

TURBULENCE AND ICING CONDITIONS

TURBULENCE AND ICING

Both normal and clear air turbulence (CAT) as well as icing pose severe threats to aircraft. Because of their importance, reprints of enclosures to NAVWEASERVCOMINST 3140.4 (reference 86) are reprinted here in their entirety to provide criteria for describing both turbulence and icing in specific terms as well as a "Guide to Turbulence Classes" to help in forecasting the location of turbulence as related to meteorological and geographical conditions.

An appendix to an FAA Advisory Circular on clear air turbulence (reference 87) is also reprinted here because of its pertinence to conditions at Point Mugu during Santa Anas and when the polar jet stream flows down or across the west coast. The use of these enclosures by PMR forecasters should be especially helpful in their briefings to pilots.

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NAVWEASERVCOMINST 3140.4
15 September 1970, reference 86

AIRFRAME ICING REPORTING TABLE

INTENSITY	ICE ACCUMULATION
TRACE	Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though de-icing/anti-icing equipment is not used, unless encountered for an extended period of time (over one hour).
LIGHT	The rate of accumulation may create a problem if flight is prolonged in this environment (over one hour). Occasional use of de-icing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the de-icing/anti-icing equipment is used.
MODERATE	The rate of accumulation is such that even short encounters become potentially hazardous and use of de-icing/anti-icing equipment or diversion is necessary.
SEVERE	The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

Pilot Report
Acft Ident, Location, Time (GMT), Intensity of Type*, Altitude/FL, Acft Type, IAS.
Example: Air Force 10634 holding at Westminster VOR, 1232Z, Light rime icing, altitude six thousand, T-29, IAS 220 kts.
*Rime Ice: Rough, milky, opaque ice formed by the instantaneous freezing of small super cooled water droplets.
Clear Ice: Glossy, clear or translucent ice formed by the relatively slow freezing of large super cooled water droplets.

NAVWEASERVCOMINST 3140.4
15 September 1970, Reference 86

TURBULENCE CRITERIA TABLE

AIRFRAME, OPERATIONAL, AND GUST

ADJECTIVAL CLASS	AIRFRAME LIMITS[1]	TRANSPORT AIRCRAFT OPERATIONAL CRITERIA[2]		GUST CRITERIA
		Descriptive	Air Speed Fluctuation	Derived Gust Velocities (U_{de})[3] the order of:
LIGHT	[illegible]	[illegible]	5 to 15 knots	5 [illegible] 20 fps
MODERATE	[illegible]	[illegible]	15 [illegible] 25 knots	20 [illegible] 35 fps
SEVERE	[illegible]	[illegible]	[illegible] than 25 knots	35 [illegible] 50 fps
EXTREME	[illegible]	[illegible]	rapid fluctuations in excess of 25 knots	more than 50 fps

[illegible]
1 [illegible]
2 [illegible]
3 [illegible]
4 [illegible]

NAVWEASERVCOMINST 3140.4
15 September 1970, Reference 86

GUIDE TO TURBULENCE CLASSES

As typically associated with meteorological conditions

EXTREME TURBULENCE - This rarely encountered condition is usually confined to the strongest forms of convection and wind shear, such as:

1. In Mountain Waves in or near the rotor cloud (or rotor action) usually found at low level leeward of the mountain ridge when the wind component normal to the ridge exceeds 50 knots near the ridge level.

2. In Severe Thunderstorms where available energy indicates the production of large hail (3/4 inch or more), strong radar echo gradients or almost continuous lightning. It is more frequently encountered in organized squall lines than in isolated thunderstorms.

SEVERE TURBULENCE - In addition to the situations where extreme turbulence is found, severe turbulence may also be found:

1. In Mountain Waves:

   a. When the wind component normal to the ridge exceeds 50 knots near the ridge level: at the tropopause* up to 150 miles leeward of the ridge.

   b. When the wind component normal to the ridge is 25-50 knots near the ridge level: up to 50 miles leeward of the ridge, from the ridge level up to several thousand feet above* and at the base of relatively stable layers below the tropopause.

   *A reasonable Mountain Wave turbulence layer is about 5000 feet thick.

2. In and near Mature Thunderstorms and occasionally in towering cumuliform clouds.

3. Near Jet Streams within layers characterized by horizontal wind shears greater than 16 knots/degree latitude (40 knots/150 nautical miles) and vertical wind shears in excess of 6 knots/1000'. When such layers exist favored locations are below and/or above the jet core and from roughly the vertical axis of the jet core to about 50 or 100 miles toward the cold side.

MODERATE TURBULENCE - *In addition to the situations where extreme and severe turbulence are found, moderate turbulence may also be found:*

1. In Mountain Waves:

   a. When the wind component normal to the ridge exceeds 50 knots near the ridge level: between the surface and about 10,000 feet above the tropopause from the ridge line to as much as 300 miles leeward.

   b. When the wind component normal to the ridge is 25-50 knots near the ridge level: between the surface and the tropopause from the ridge line to as much as 150 miles leeward.

2. In, near, and above Thunderstorms and in towering cumuliform clouds.

3. Near Jet Streams and in Upper Trough, Cold Low, and Front Aloft situations where vertical wind shears exceed 6 knots/1000' or horizontal wind shears exceed 7 knots per one degree latitude.

APPENDIX

RULES OF THUMB TO ASSIST IN AVOIDING OR MINIMIZING ENCOUNTERS WITH CLEAR AIR TURBULENCE.*

From FAA Advisory Circular AC 00-30, March 5, 1970 Reference 87

Note: The following rules of thumb have been developed for westerly jet streams.

1. Jet streams stronger than 110 knots (at the core) are apt to have areas of significant turbulence near them in the sloping tropopause above the core, in the jet stream front below the core, and on the low-pressure side of the core. In these areas there are frequently strong wind shears.

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*CAT is officially defined as "all turbulence in the free atmosphere of interest in aerospace operations that is not in or adjacent to visible convective activity (this includes turbulence found in cirrus clouds not in or adjacent to visible convective activity)." This definition was published in the Department of Commerce Report of the National Committee for Clear Air Turbulence dated December 1966.

2. Wind shear and its accompanying clear air turbulence in jet streams is more intense above and to the lee of mountain ranges. For this reason, clear air turbulence should be anticipated whenever the flight path traverses a strong jet stream in the vicinity of mountainous terrain.

3. On charts for standard isobaric surfaces, such as 300 millibars, if 20-knot isotachs are spaced closer together than 60 nautical miles, there is sufficient horizontal shear for CAT. This area is normally on the poleward (low-pressure) side of the jet stream axis, but in unusual cases may occur on the equatorial side.

4. Turbulence is also related to vertical shear. From the winds-aloft charts or reports, compute the vertical shear in knots-per-thousand feet. If it is greater than five knots-per-thousand feet, turbulence is likely. Since vertical shear is related to horizontal temperature gradient, the spacing of isotherms on an upper air chart is significant. If the 5°C isotherms are closer together than two degrees of latitude (120 nautical miles), there is usually sufficient vertical shear for turbulence.

5. Curving jet streams are more apt to have turbulent edges than straight ones, especially jet streams which curve around a deep pressure trough.

6. Wind-shift areas associated with pressure troughs are frequently turbulent. The sharpness of the wind-shift is the important factor. Also, pressure ridge lines sometimes have rough air.

7. In an area where significant clear air turbulence has been reported or is forecast, it is suggested that the pilot adjust the speed to fly at the recommended rough air speed on encountering the first ripple, since the intensity of such turbulence may build up rapidly. In areas where moderate or severe CAT is expected, it is desirable to adjust the air speed prior to the turbulence encounter.

8. If jet stream turbulence is encountered with direct tailwinds or headwinds, a change of flight level or course should be initiated since these turbulent areas are elongated with the wind, and are shallow and narrow.

9. If jet stream turbulence is encountered in a crosswind, it is not so important to change course or flight level since the rough areas are narrow across the wind. However, if it is desired to traverse the clear air turbulence area more quickly, either climb or descend after watching the temperature gauge for a minute or two. If temperature is rising - climb; if temperature is falling - descend. Application of these rules will prevent following the sloping tropopause or frontal

surface and staying in the turbulent area. If the temperature remains constant, the flight is probably close to the level of the core, in which case either climb or descend as convenient.

10. If turbulence is encountered in an abrupt wind-shift associated with a sharp pressure trough line, establish a course across the trough rather than parallel to it. A change in flight level is not so likely to alleviate the bumpiness as in jet stream turbulence.

11. If turbulence is expected because of penetration of a sloping tropopause, watch the temperature gauge. The point of coldest temperature along the flight path will be the tropopause penetration. Turbulence will be most pronounced in the temperature-change zone on the stratospheric (upper) side of the sloping tropopause.

12. Both vertical and horizontal wind shear are, of course, greatly intensified in mountain wave conditions. Therefore, when the flight path traverses a mountain wave type of flow, it is desirable to fly at turbulence-penetration speed and avoid flight over areas where the terrain drops abruptly, even though there may be no lenticular clouds to identify the condition.

NOTE: In this country, civil forecasts of areas of clear air turbulence are made by the Weather Bureau (National Weather Service) and disseminated (1) in Area Forecasts (FA) over teletypewriter Service A every six hours, (2) on High Level Significant Weather facsimile charts available every six hours, and (3) on a non-scheduled basis as In-Flight Advisories (AIRMETS and SIGMETS). In-flight advisories are transmitted over Service A when moderate or greater CAT is forecast or when severe or extreme CAT has been reported. These are made available to aircraft over FSS radio, and, in addition, SIGMET Alerts are broadcast by en route traffic controllers.

CHAPTER 14. SELDOM-OBSERVED PHENOMENA

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CHAPTER 14

THUNDERSTORMS

Occurrence

Thunderstorms in the vicinity of or at Point Mugu are relatively rare—only about 2 or 3 occurrences are reported in an average year. Even during active years, a maximum of only 5 have ever been reported; in some years there have been none.

Studies of the 54 occurrences of lightning or thunder reported near or at Point Mugu from 1949-1968 (reference 18) reveal two peaks of maximum occurrence. One is during the late summer and early fall and the second is in mid to late winter. The "summer" peak (September and October, together account for about one-third of all cases) is due to tropical air being advected into the area at higher levels b southeasterly flow. Such thunderstorm activity is usually confined to the mountains and deserts, but occasionally it occurs at the coast. The "winter" maximum (January, February, and March account

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for another one-third of all cases) is due to very unstable air occurring with active frontal systems or cold lows.

There appears to be a diurnal preference for thunderstorms as well, with nearly half the occurrences of lightning or thunder beginning between the hours of 1800 and midnight and only 22% of such occurrences beginning during the hours of 0600 through 1700. Of more significance is the relatively short life of thunderstorm activity in the Point Mugu area. Seventy percent of reported cases were observed to last for periods of less than 2 hours. Never in the 20-year period studied was there more than 24 hours of recorded thunderstorm activity during a single episode.

As would be expected, when thunderstorms do occur, they seem to be somewhat more frequent and intense over the nearby coastal mountains.

Forecasting

Thunderstorms are very difficult to forecast at Point Mugu because of their infrequency. In summer, if winds aloft are from the southeast and if satellite photos or hourly reports reveal extensive cloud masses upwind of the station, thunderstorms should be considered. In winter, thunderstorms should be considered at the time of passage of very active fronts or when very cold troughs or upper lows (temperatures of -30°C or less at 500 mb) pass over the station.

FUNNEL CLOUDS

Funnel clouds are rare in the Point Mugu area, occurring with a frequency of probably less than one per year. They have been officially recorded seven times in Point Mugu records. In none of these cases did a funnel cloud touch down over land to constitute a tornado, although one of them touched down over water to form a waterspout. As might be expected, their occurrence is limited to cases of very cold troughs or cold lows where there is great instability and heavy cumulus clouds are produced (for some reason, west coast funnel clouds occur more often with heavy cumulus than cumulonimbus clouds). Funnel clouds in the local area are most frequently sighted hanging down part way f[illegible]rge buildups over the waters to the east-sout[illegible] through southwest. The funnels usually disappear as the clouds move onshore, but cyclonic gusty winds may still blow at the station and Laguna Peak when the cloud and shower moves overhead. Turbulence in such situations is most likely severe. On April 1, 1968, a funnel cloud occurred briefly over the waters to the southwest and then reappeared over land to the east and northeast of the station as the spawning cloud moved inland (figure 14-1). The funnel appeared and disappeared, changing shape several times, but always remained nearly horizontal and never touched the ground.

The occurrence of funnel clouds in the local area is too infrequent to permit development of forecast rules. However, forecasters should be aware of the possibility of funnel cloud development during cold low weather when heavy cumulus clouds develop over the water and move onshore.

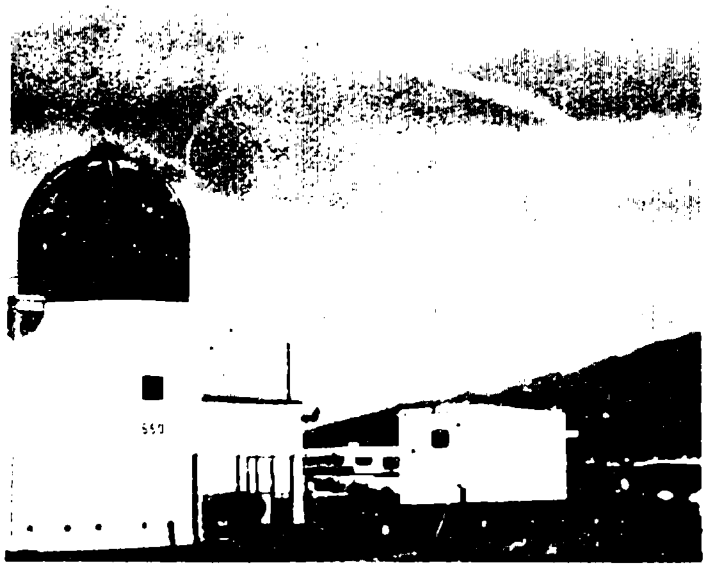

Figure 14-1. Funnel Cloud Near Point Mugu at 0900 PST, 1 April 1968. (Photo by R. A. Helvey.)

SNOW

Snow is probably the rarest of important weather phenomena at Point Mugu, although it is a yearly occurrence in the mountains to the north. At Point Mugu, snow has been recorded only three times in 22 years (1949, 1957, and 1962), and only once was measurable snow produced. That was in January 1949, when 2 inches fell and lasted through the night and morning hours. At the same time, a trace of snow was recorded at San Nicolas Island.

There are several common characteristics to the three snow occurrences. In each case, a cold upper low developed over southern California with a large steep ridge aloft poking into the northeast Gulf of Alaska. The result was a strong northeast flow aloft which resembled the gross patterns of Santa Ana situations as described under "Special Cases of Santa Ana-Like Patterns, Cyclonic Santa Anas." Figures 5-19 and 5-20 show the surface and 500-mb situations during the measurable snowfall of 1949.

As the cold northeast flow aloft moved over southern California, it fed new cold air into the unstable cyclonic circulation so that the upper low was maintained. Beneath it, at the surface, low-pressure centers formed over or just off southern California while strong high pressure of Arctic origin spread all the way from the Gulf of Alaska to the cold continent. The strong Santa Ana-like northeast flow was also present at the surface, and kept low-level temperatures cold enough to allow the precipitation to reach the ground as snow, or snow mixed with rain, although actual surface temperatures were well above freezing for the most part during all three occurrences. In the 1962 episode, snow fell with a surface temperature of 43 degrees.

A last characteristic common to all three snow occurrences was that they all occurred during January. This is not coincidental since January is generally the coldest of the winter months. Unstable, cold lows in other months and years have been too warm to result in snow at sea level.

APPENDIX A

500-MILLIBAR VORTICITY AS A LOCAL FORECASTING AID

VORTICITY

Vorticity is a measure of local (particle) rotation in a fluid flow and can be a helpful forecasting tool (reference 88). In the atmosphere, two components make up vorticity: (1) the amount of isobar or contour (windflow) curvature, and (2) shear in the wind. At certain times vorticity may be nearly all manifested in one of these components, but there is always some portion of both. Curvature is most often mistaken for the whole of vorticity because it is much easier to recognize on a weather map, and often curvature is the more important of the two insofar as Point Mugu weather is concerned.

Vorticity is more useful to the forecaster in the rainy season because most rain-producing disturbances are often characterized by a sharp vorticity

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maximum or region of PVA (positive vorticity advection) that can be seen progressing steadily downstream toward the PMR area. Thus, when the forecaster is able to predict the continued movement of the vorticity feature, he may correctly forecast rain at Point Mugu. In addition, clearing conditions commonly follow the passage of a vorticity maximum. However, when there is a large mean trough over the area, there will be a succession of PVAs and vorticity maximums passing through the Point Mugu area with only temporary or partial clearing following each one.

When vorticity is used as a forecast aid for summer fog and stratus at Point Mugu, it is best used only as a general indicator of cyclonic and anticyclonic conditions which in turn suggests certain vertical motion fields. The vorticity value by itself is of no help in forecasting summer stratus.

There are two frames of reference for vorticity: One is vorticity relative to a fixed plane, which for our atmosphere is the earth; the second is vorticity in a total sense (absolute vorticity), which is relative vorticity plus the vorticity of the earth's rotation.

Relative Vorticity

Figure A-1 shows the shear portion of relative vorticity, that vorticity which is relative to a fixed point on the earth. The straight lines with arrows represent a windflow from west to east. Line length

is a measure of windspeed; longer lines represent stronger winds. This illustration is similar to a typical jet stream or wind maximum. Point A is to the north of the strongest wind and is therefore in the region of rotation in a cyclonic sense because air to the south is moving faster than air to the north of point A. Since relative vorticity is being discussed, cyclonic vorticity may be considered positive; therefore the vorticity values at point A are positive.

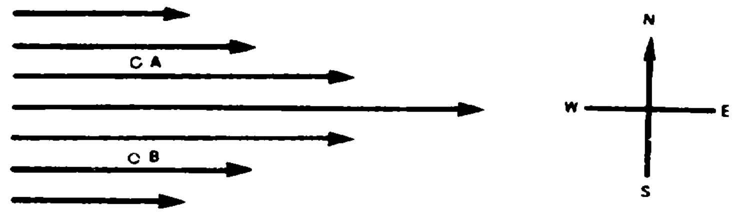


Figure A-1. Relative Vorticity of Wind Shear.

Point B shows the opposite of A: the wind increases to the north and decreases to the south, and so the sense of rotation at B is anticyclonic and the vorticity there would be negative.

Figure A-2 shows relative vorticity due to curvature in the windflow, a typical trough, and a ridge. Curvature is important to the forecaster because, if a trough lies just to the west of Point Mugu, there would be southerly winds aloft caused by the curvature of the windflow, which bring in moisture to produce middle clouds and rain. Thus, a further increase in cyclonic curvature would probably result in more rain but a further increase is cyclonic shear might result in little noticeable effect.

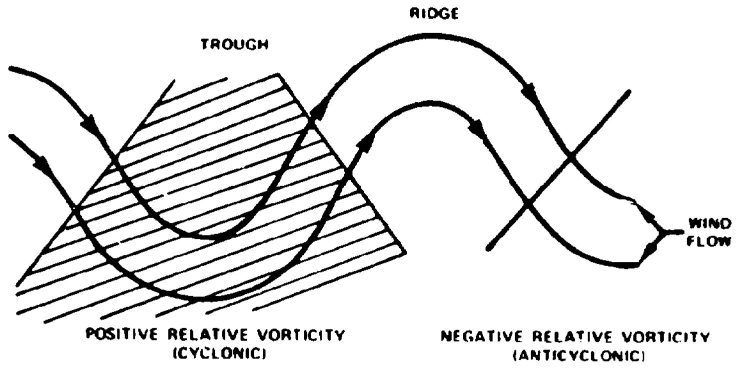


Figure A-2. Relative Vorticity Due to Curvature in Windflow.

In some instances, curvature and shear of the windflow may combine to form a large (positive or negative) relative value of vorticity, as seen in figure A-3(a). However, sometimes the elements of vorticity are of opposite sense (figure A-3(b), and they will cancel out each other and result in a small or near-zero value of vorticity. (Notice in figure A-3(a) how the lines are compressed at the lower part of the troughs and upper part of the ridge but the opposite is shown in figure A-3(b).) This figure shows why some troughs that are visible on a weather map may look promising for some change in local

weather because of the sharpness of curvature, but if the sense of shear is anticyclonic, the vorticity will be small and the net result is a trough with no marked weather change.

(a) Large Positive and Negative Relative Vorticity Values.

(b) Small Positive and Negative Relative Vorticity Values.

Figure A-3. Shear and Curvature Combined in Vorticity.

Absolute Vorticity

Cyclonic vorticity has thus far been considered to be positive and anticyclonic vorticity negative, since the discussion has been on relative vorticity only. However, because the earth is rotating, the extra rotational effect on the horizontal plane caused by the earth's rotation must be added to the relative vorticity. The value is then absolute vorticity, that is analyzed on the numerical weather charts, where values shown are positive. The extra amount of vorticity caused by the earth's rotation (earth vorticity) ranges in value from zero at the equator to a maximum at the poles. It is always positive in the Northern Hemisphere and if this is added to positive relative vorticity, the result is a larger positive number. However, if the earth's positive relative vorticity value is added to a negative relative vorticity, the resulting value is usually a small positive number. On the weather charts, lows appear as vorticity maximums, and highs or ridges appear as vorticity minimums. Negative values of absolute vorticity are rare and when they do occur they signify great anticyclonic relative vorticity.

Changes in Vorticity Patterns

On most vorticity weather charts, including the ones used in the Geophysics Division, the horizontal surface upon which vorticity is computed is taken to be the 500-mb level, which is also approximately the level of nondivergence. The set of solid lines on these charts represents values of absolute vorticity; the set of broken lines represents the 500-mb height contours pattern, i.e., the 500-mb windflow. If the assumption is made that the isotherms and height contours at this level are in phase and there is not really any divergence at this level, then the atmosphere is barotropic and the local change of vorticity can be forecast to take place in accordance with certain simple principles. Briefly, a parcel of air in a barotropic atmosphere keeps or maintains whatever absolute vorticity it started with. Thus, as air parcels with certain values of absolute vorticity move or are advected by the windflow, they take with them whatever

vorticity they originally had. But if in the course of their traveling they change latitude--thereby changing their value of earth vorticity--they must make a corresponding change in their relative vorticity to keep their absolute vorticity constant. Therefore, parcels of air moving with a north wind will tend to gain a more cyclonic value to their relative vorticity and parcels of air moving with a south wind will tend to gain anticyclonic (or lose cyclonic) relative vorticity. If the combined effects of vorticity advection and change of latitude are visualized as showing up primarily in the curvature of the windflow, the 500-mb contour pattern can change with time as shown in the example of figure A-4. In figure A-4(a), a small amplitude trough and ridge is shown in the dashed height contour lines which can also represent the 500-mb windflow. A vorticity maximum with a center of "18" and a vorticity minimum with a center of "2" located farther downstream is superimposed on this flow. Figure A-4(b) shows the pattern or map at some time later, say after 24 hours, during which time the vorticity maximum or center of cyclonic rotation and the vorticity minimum or center of anticyclonic rotation have been advected by the 500-mb windflow. The centers have been moved intact, but the 500-mb flow pattern is now changed. The trough has become sharper since the trough line has increased in absolute vorticity and also since the air in the vorticity maximum is at a lower latitude and must therefore gain relative vorticity to maintain its absolute vorticity. The ridge has also grown in amplitude because less absolute vorticity has been advected onto the ridge line and because the air in the vorticity minimum has traveled northward (gaining earth vorticity) and must lose relative vorticity to maintain its absolute vorticity.

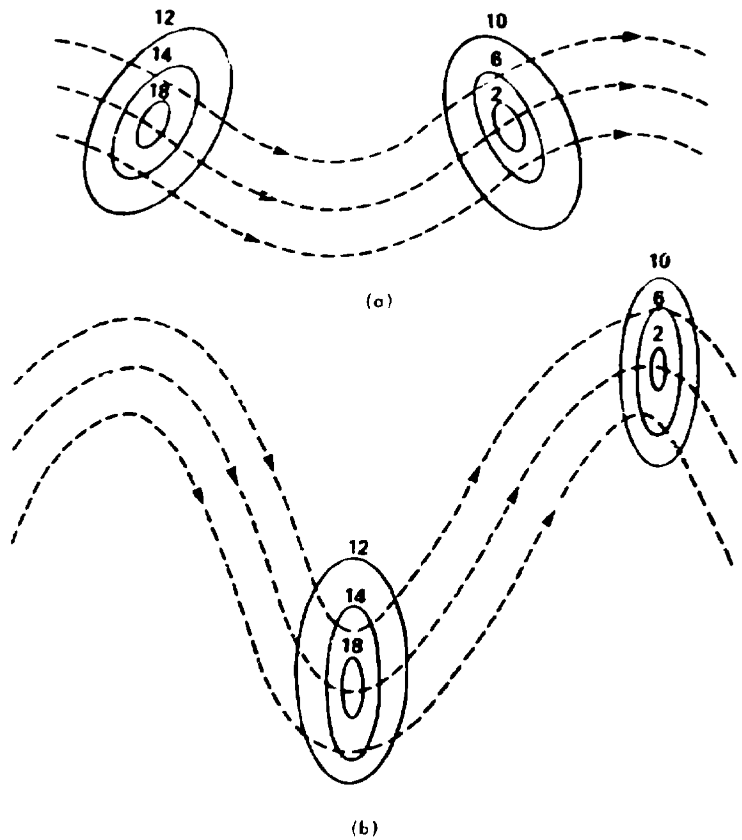


Figure A-4. Changing 500-Millibar Contour Pattern Over 24-Hour Period.

It may seem incongruous for a vorticity maximum to be superimposed on an *anticyclonic flow* of a ridge. Although troughs generally have higher vorticity values and ridges lower vorticity values, there are short waves *superimposed* on the long- or major-wave pattern.

Wave Growth

A short-wave trough may be discernible by a *slight flattening* at the top of a ridge and a short ridge by a slight flattening at the *bottom of a trough*. On the vorticity charts, these short waves are better seen as vorticity maximums and minimums. As the vorticity centers are moved along by advection and the short-wave *trough finally* coincides with the next long-wave trough; and similarly when the short-wave ridge coincides with the next long-wave ridge, the long waves will grow as shown in figure A-4. Some of this growth is due to advection of vorticity to the trough and ridge lines and some of it is due to conversion of earth vorticity to relative vorticity.

There is one special case of wave growth which is very pertinent to local weather at Point Mugu and in fact to all southern California. Sometimes in the late fall through spring months, a fairly large amplitude ridge builds into the Gulf of Alaska. Assuming that the downwind trough has already passed Point Mugu with a little rain and cloudiness followed by clearing, the synoptic pattern would look something like figure A-5 where the dashed lines again represent the 500-mb flow *pattern*. *From this map*, the trough would be expected to continue to move eastward and the ridge to move onto the coast to bring warmer *temperatures--perhaps* even a Santa Ana. Now suppose that a strong, narrow jet stream develops on the northern perimeter of the ridge. From the reasoning before, there would then be a region of great anticyclonic vorticity located just south of the jet stream caused by both the shear and the curvature of the windflow. If the wind is strong enough and the curvature sharp enough, the *absolute* vorticity at the top of the ridge could be *near* zero. Air traveling downstream around the sharp unstable ridge *would* try to maintain its absolute vorticity of zero and would *begin to cut into* the downwind trough. As adjacent air becomes entrained into the flow, the trough will begin to deepen and cut back again to the west (figure A-5(b)). Finally, after the air of near zero absolute vorticity has moved around the ridge, a cutoff low with a center just off the coast will develop and instead of fair and warm weather at Point Mugu with north winds aloft, there will be deteriorating and cooler weather with south or southeast winds aloft (figure A-5(c)). As the low stagnates over the region for a day or two, the southerly winds will bring in enough moisture to cause numerous instability showers with freezing levels lowering to 3,000 to 4,000 feet or lower. The contour patterns illustrated in figure A-5(c) are similar in many respects to the situations during the three snow occurrences at Point Mugu as discussed previously under "Snow" and shown in figures 5-19 and 5-20.

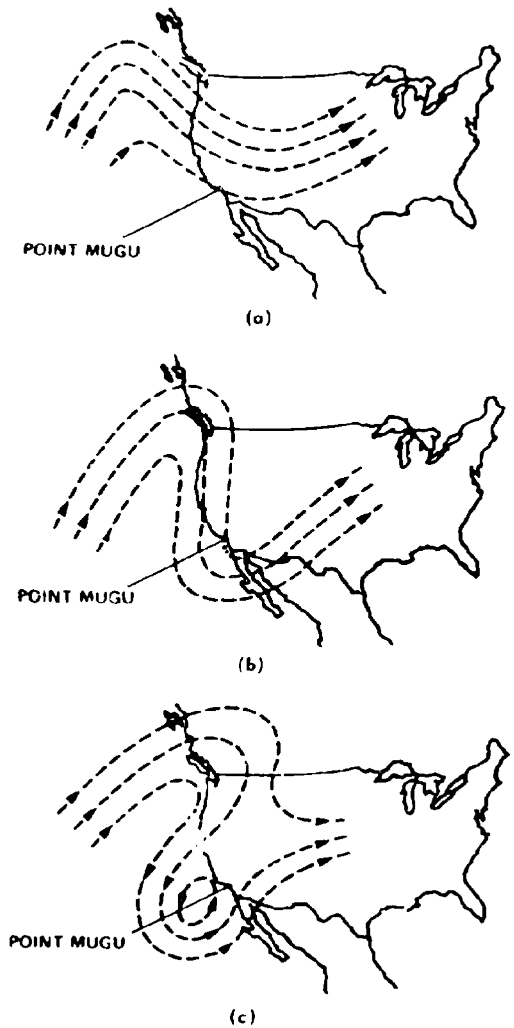


Figure A-5. Unstable Ridge in Gulf of Alaska.

Closed lows are experienced under many different situations, even in summer although they are then quite weak. Because they are closed systems, they all have one thing in common: the vorticity is moved round and round the center and thus does not really become advected out of the low (figure A-6). This is why closed lows and closed highs move very slowly, if at all, and present likely blocking situations to the forecaster.

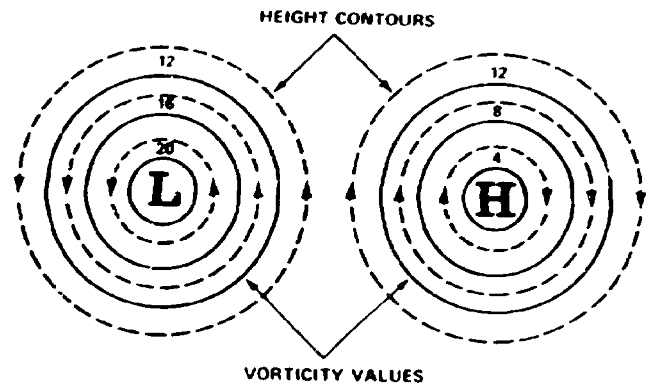


Figure A-6. Vorticity in Closed Systems.

Development and Dissipation

In the above chain of events, it is assumed that no vorticity has actually been created, that is, either added to or subtracted from the systems. This would be true for barotropic processes. When the atmosphere is not barotropic it is called baroclinic. In

such an atmosphere, the isotherms and height contours are out of phase with each other (i.e., they intersect), there is divergence and convergence of flow, and the absolute vorticity of individual air parcels do not have to be conserved. In these situations, development or dissipation takes place.

When there is development (or dissipation) new vorticity is created and added to a system, or old vorticity is destroyed. The most common processes that lead to development or dissipation are warming and cooling. If the isotherms and height contours are not in phase with each other. there will be advection of warm or cold air into the system.

In figure A-7, there is cold advection to the rear of a trough which would cause the trough to develop. Warm advection would destroy it. On the other hand, warm advection into the ridge would further build the

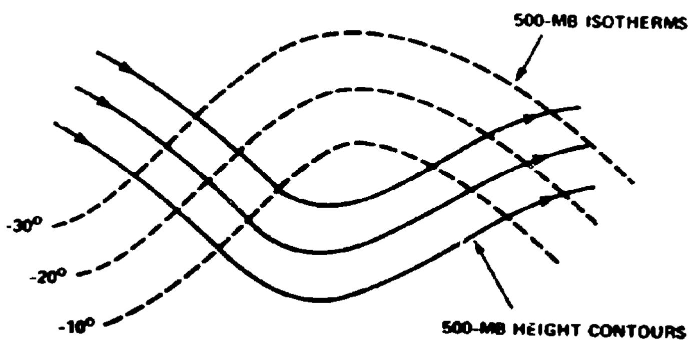


Figure A-7. Development of Systems Caused by Thermal Advection.

ridge and cold advection would destroy it. Thus cold advection into a trough creates cyclonic vorticity and warm advection into a ridge creates anticyclonic vorticity. When moving systems develop because of warm or cold advection, they usually slow down in forward speed.

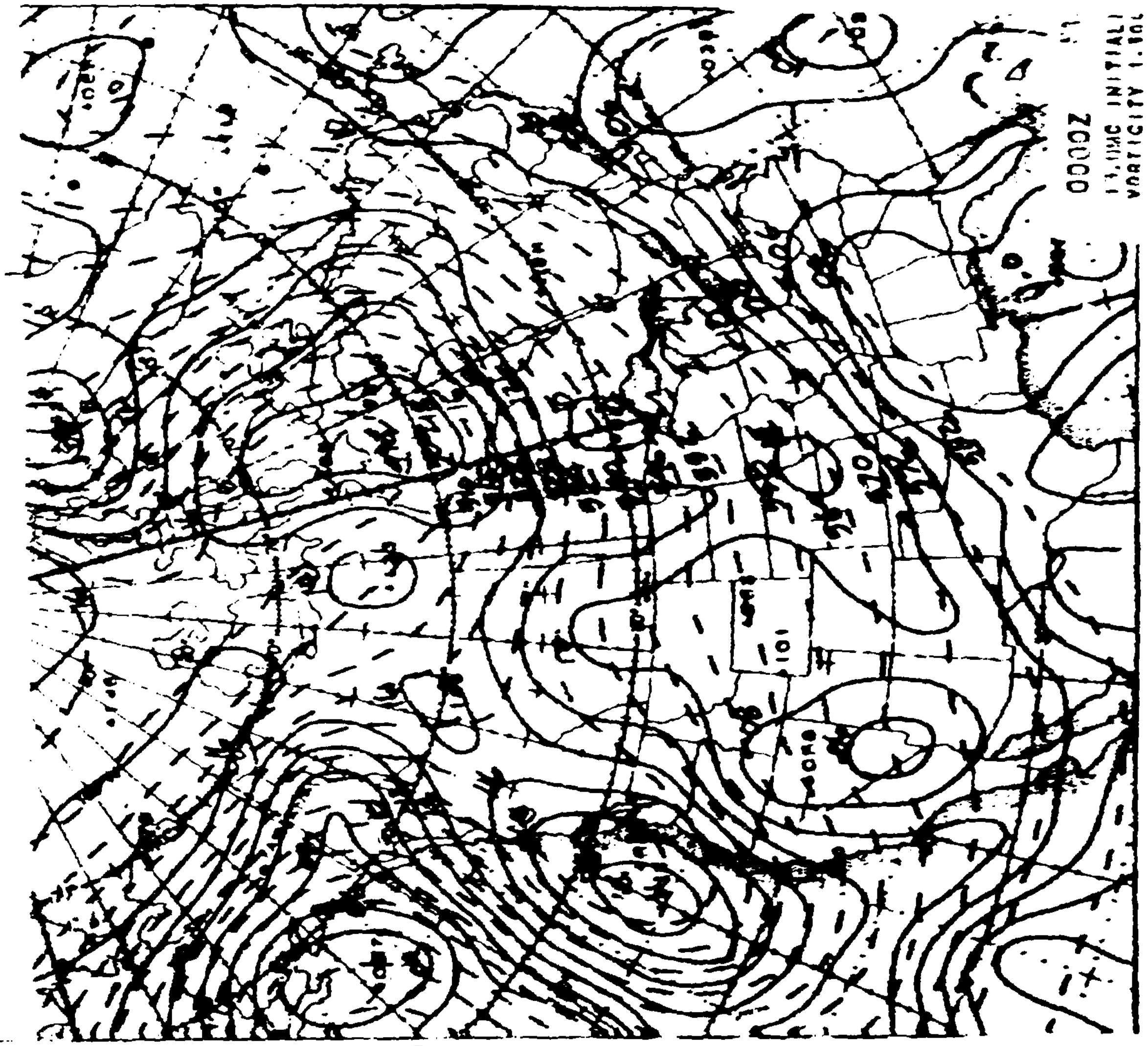
Positive and Negative Vorticity Advection

In applying vorticity to make forecasts, it is not enough to know the actual value--partly because the forecaster cannot know how it is separated into shear and curvature until he looks at the windflow. Even more important, he must know what the trend of vorticity will be and whether Point Mugu will be influenced by PVA (positive vorticity advection) or NVA (negative vorticity advection).

Perhaps the most useful vorticity feature available for forecasting rainfall is a frequently seen region of strong vorticity gradient on either side of a vorticity maximum. Ahead of the vorticity maximum this region of strong packing of iso-vorticity lines corresponds to a region of strong positive vorticity advection. The region of strong gradient to the rear is one of negative vorticity advection. The former is extremely important because it is coincident with the region of frontal activity and hence of moderate and heavy rain. Only when the peak value in a vorticity maximum is extremely high is there any appreciable precipitation associated with its location over the station. Nearly all the significant precipitation

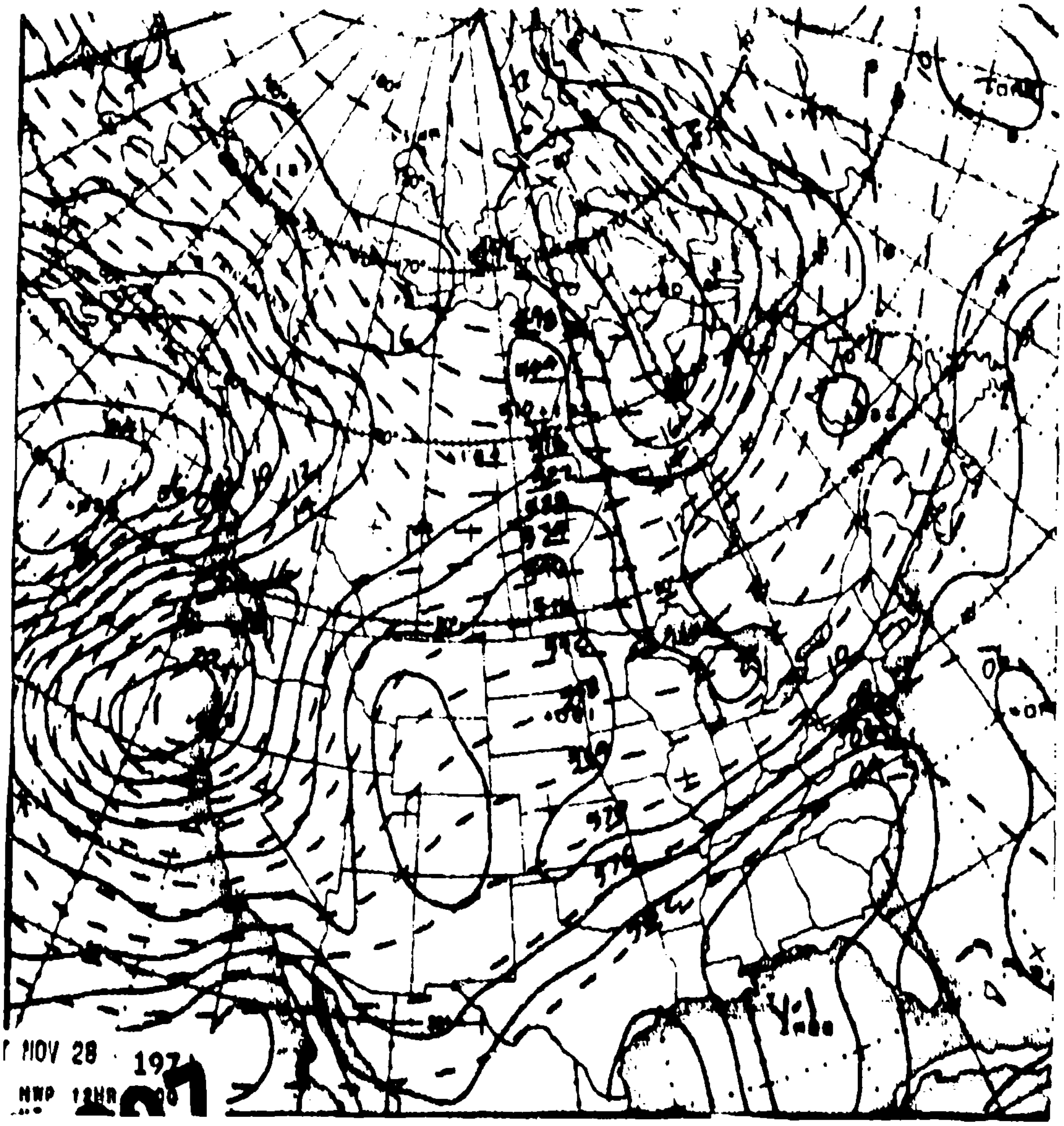
and weather associated with deep frontal troughs occurs before surface frontal passage and within the region of strong positive vorticity advection (and vorticity gradient ahead of the trough). The best forecasts of rain onset and ending can be made by forecasting the time of arrival and passage of these regions of strong PVA. This is illustrated in an excellent example and sequence of events presented in figures A-8(a), (b), (c), and (d) for the heavy rains of Thanksgiving weekend, 1970. In figure A-8(a), a strong vorticity maximum with peak value of 20 is located off the coast of Washington at 0000Z on 28 November. The region of strongest gradient of vorticity lies across the Pacific Northwest. At the time, Point Mugu observed both NVA and small vorticity values and a few scattered clouds on official observations. Figure A-8(b) shows the 12-hour prognosis verifying 1200Z on 28 November. It shows PVA over most of the California coast with the pretrough region of strongest vorticity gradient over northern California. The vorticity maximum itself is still off the Oregon-California coast. At the time this prognosis was to verify, very light drizzle began to fall at Point Mugu. Figure A-8(c) shows the 24-hour prognosis which was to verify at 0000Z on 29 November. It shows a tightening vorticity gradient over most of California with the tightest region of packing across the center of the state. The vorticity maximum itself was still "progged" to be off the northern California coast. At Point Mugu, moderate rain began falling 2 hours before the prognosis verification time indicating excellent agreement with actual observations. Finally, figure A-8(d) shows the 36-hour vorticity prognosis which was to verify at 1200Z on 29 November. It shows an extremely strong vorticity gradient passing through southern California. This showed excellent agreement with actual observations of the passage of the front and heaviest rain at Point Mugu. At the station, the front apparently passed about 1700Z with abrupt wind changes from strong southeast (peak gust 42 knots) to west. Up to that point, nearly all of the storm total of 3.57 inches had fallen at Point Mugu. Of the total amount, only 0.34 inch could be attributed to postfrontal showers over the next 24 hours associated with passage of the vorticity maximum and the trough aloft. Note that the 36-hour prognosis also indicated that the vorticity maximum would still be off the central California coast at the time of passage of the maximum vorticity gradient through southern California. This would be to the rear of the front where clearing normally occurs.

In short, the region of strong vorticity gradient ahead of an active trough is by far a much better tool in forecasting frontal weather conditions and rain than the actual value of vorticity itself or the passage of the vorticity maximum. Forecasters should also be wary of approximating PVA by calculating local vorticity change over some specified time period. It is quite possible for the actual vorticity value at Point Mugu to be exactly the same on two successive 12-hour vorticity prognoses and yet to have had a region of strong vorticity gradient "progged" to pass the local area sometime in between.



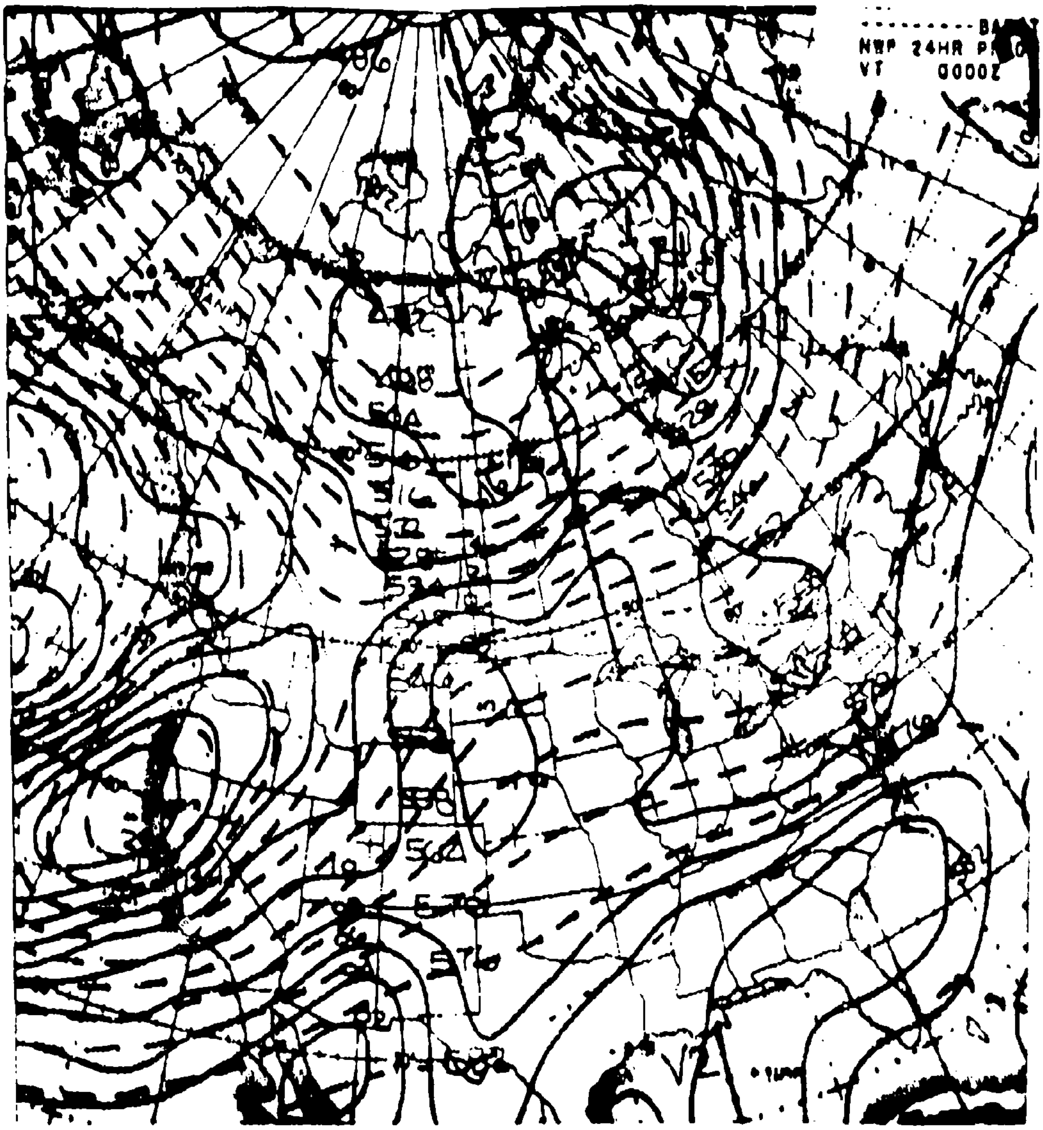
(a) Analysis at 0000Z, 28 November 1970.

Figure A-8. National Meteorological Center Barotropic Vorticity Analyses and Prognoses.



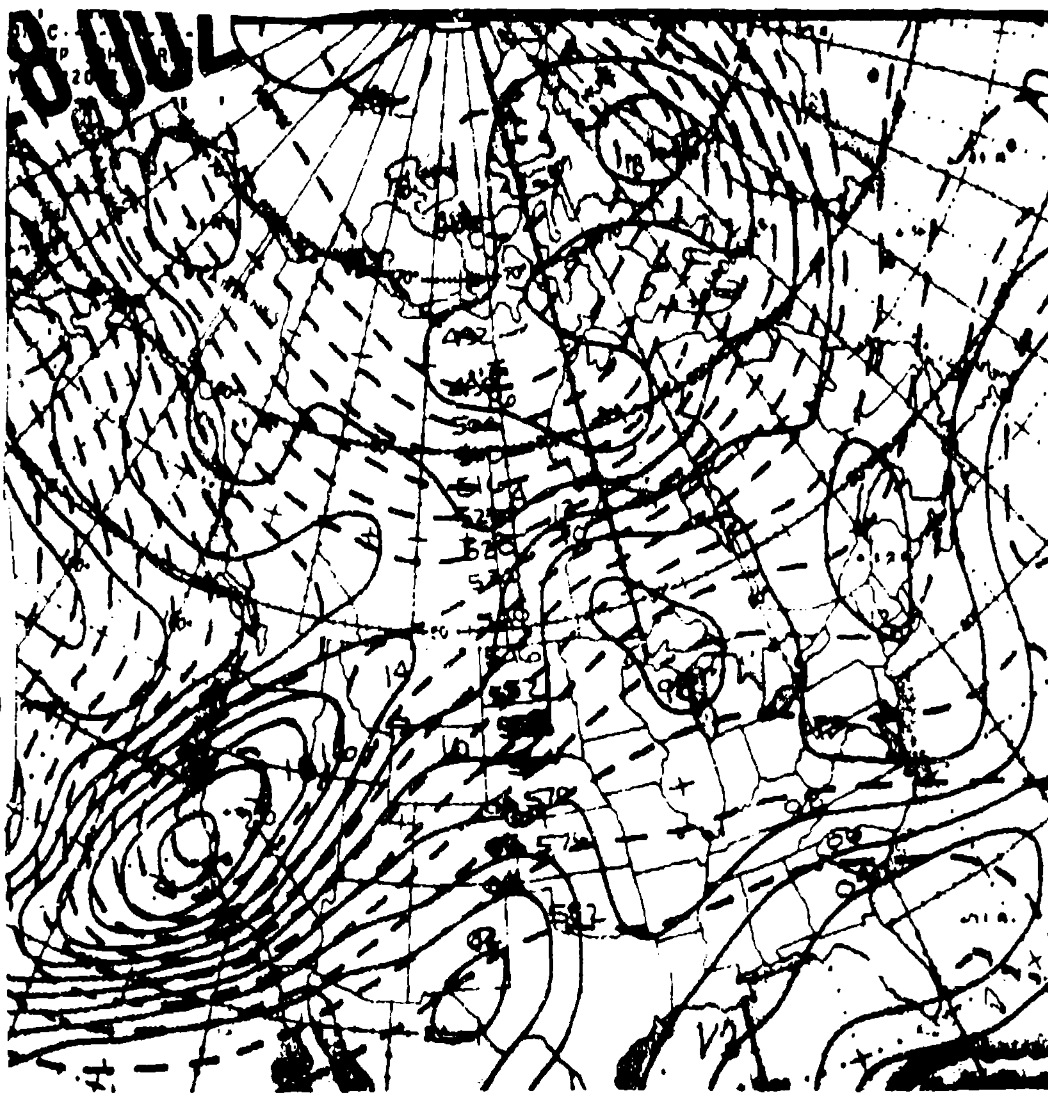
(b) 12-Hour Prognosis Verifying at 1200Z, 28 November 1970.

Figure A-8. Continued.



(c) 24-Hour Prognosis Verifying at 0000Z, 29 November 1970.

Figure A-8. Continued.



(d) 36-Hour Prognosis Verifying at 1200Z, 29 November 1970.

Figure A-8. Concluded.

Vorticity Versus Vertical Velocity

One point worthy of mention here is that vorticity should never be confused with vertical velocity. Whereas vorticity maximums and minimums often coincide with the centers of lows and highs, respectively, there is rising motion between the ridge line and the upwind trough line (region of strong vorticity gradient) and sinking motion between the trough line and the upwind ridge line. The strongest rising and sinking motions occur ahead and behind the trough (where vorticity gradients are greatest) with zero values occurring on the trough line or center of the low itself (see figure A-9). It can be seen from the figure that a vorticity maximum is not a center of rising motion because in fact there is neither rising nor sinking motion at the center of this vorticity pattern. However, just ahead of the trough, a sharp maximum is seen in rising motion and just to the rear of the trough an area of very large sinking motion is seen.

When vorticity is used to help forecast summer fog and stratus at Point Mugu, it is best used only as a general indicator of cyclonic and anticyclonic conditions which, in turn, imply certain corresponding weak vertical motion fields.

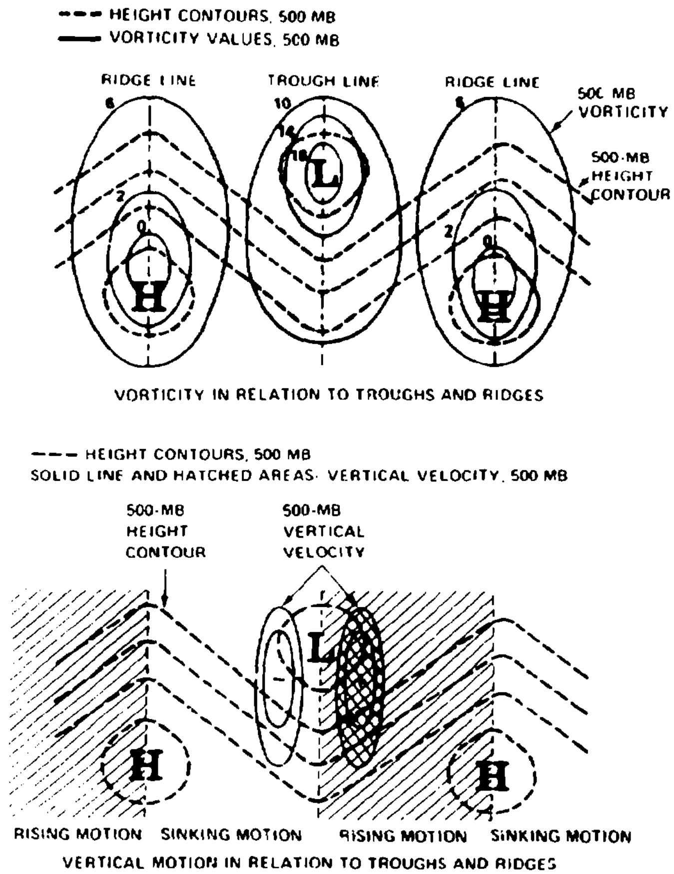


Figure A-9. Vorticity and Vertical Motion in Wind Field.

APPENDIX B

SURF FORECASTING METHODS FOR THE POINT MUGU-PORT HUENEME AREA

SYMBOLS

a_o	The angle the deepwater waves make with the depth contours
a_b	Breaker angle
c_g	Group speed of the waves
D	Decay distance
d_b	Depth of breaking
d_b/H_o	Breaker depth index
$d_w d_w$	Direction from which deepwater waves travel
F	Fetch distance
H_b	Significant breaker height
H_b/H_o	Breaker height index
H_D	Wave height at end of decay distance
H_F	Wave height at end of fetch
H_o	Deepwater swell (wave) height
H_o'	Swell height corrected for refraction
H_o/T_o^2	Deepwater wave steepness index
K_d	Refraction factor
L_b	Breaker wavelength
L_o	Deepwater wavelength
T_o	Deepwater wave period approaching beach
T_D	Wave period at end of decay distance
T_F	Wave period at end of fetch
U	Windspeed
W_f	Width of the surf zone in feet
W_y	Width of the surf zone in yards

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> NOTE:
>
> Most of the text, tables, and graphs in this appendix were taken from various standard publications (references 89 through 94) which are itemized in the reference listing at the end of this handbook.

The area to be discussed in this appendix is shown in figure B-1.

The determination of future surf conditions is based on forecast values of various deepwater sea surface variables. Once values for these variables are decided upon, the determination of surf is a mechanical and mathematical procedure. There are several aids for forecasting sea conditions: forecasts based on meteorological conditions (wind), statistical considerations, and existing sea conditions (observations). The individual forecaster will combine these aids in different ways in determining the required forecast values of deepwater swell height (H_o), wave period (T_o), and direction of deepwater wave travel ($d_w d_w$). It is extremely important that these values be carefully determined, since once they are decided, the surf conditions are determined by merely inserting values into tables, graphs, and formulas. Information in the following paragraphs will aid the forecaster in determining surf forecasting values.

DETERMINATION OF DEEPWATER VARIABLES H_o, T_o, and $d_w d_w$

1. If there are enough sea-state observations to determine the existing conditions at some remote area and you desire to determine when these waves will reach the local area and what their characteristics will then be, proceed as follows:

   a. Use the existing conditions at the remote area for entering values of H_f (height) and T_f (period) in figure B-2. Obtain the fetch, F, along the bottom scale from the point of intersection of the H_f (heavy dashed lines) and T_f (heavy solid lines) under consideration. Use this value for F_{min} in figure B-3.

   b. Use the instructions contained in figure B-3 to determine values of H_D and T_D. These will be the conditions expected in the local area as a result of waves traveling from the remote area. Hence, T_o the deepwater wave period approaching the beach will equal T_D if the decay distance (D) is the distance from the remote area to the local area. Values of H_D and T_D determined from figure B-3 can be used for values of H_o and T_o on the Surf Forecast Worksheet.

   c. With T_D and decay distance (D) determine the travel time of the waves from the remote area to the local area from figure B-4.

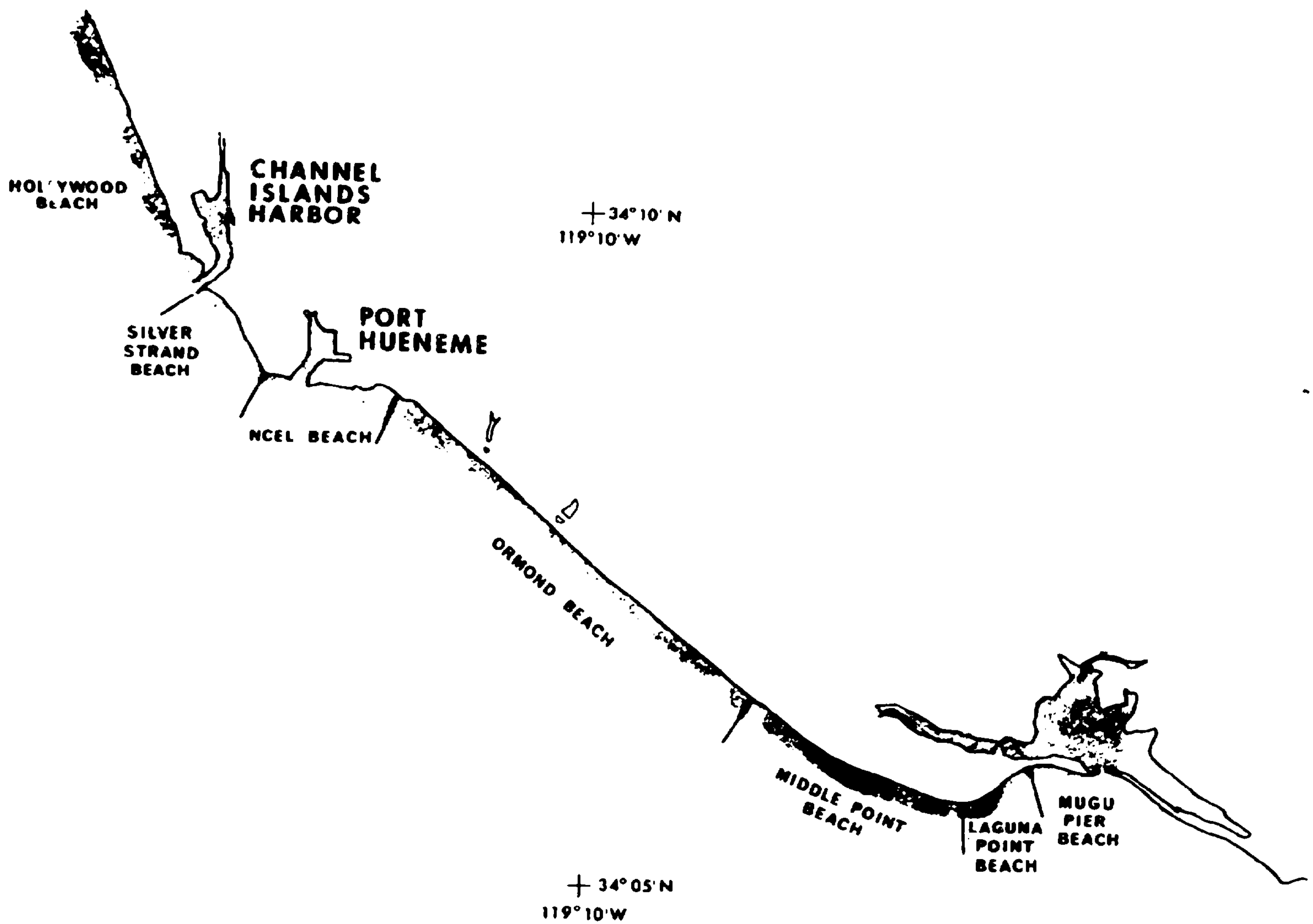


Figure B-1. Point Mugu–Port Hueneme Beach Areas.

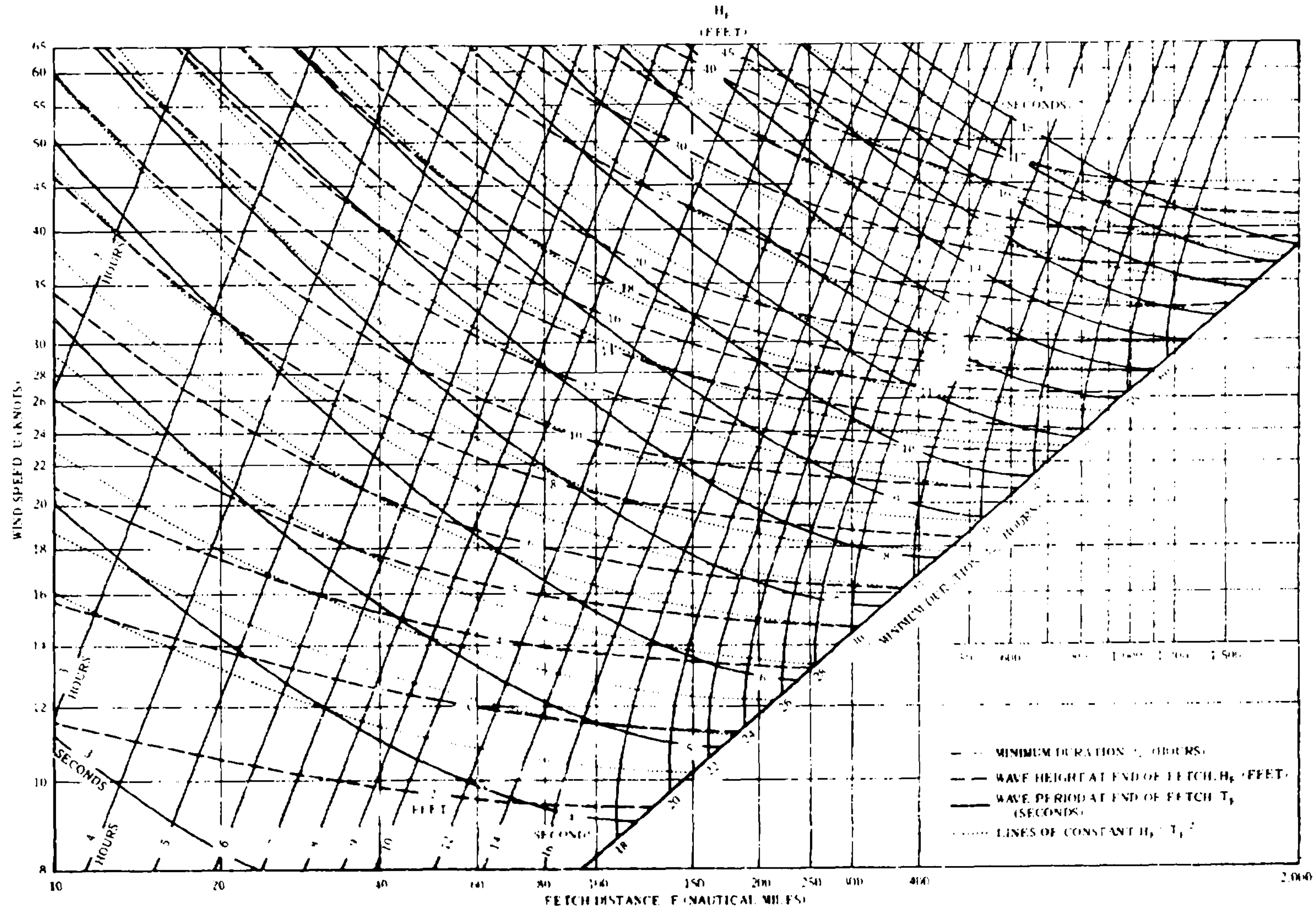
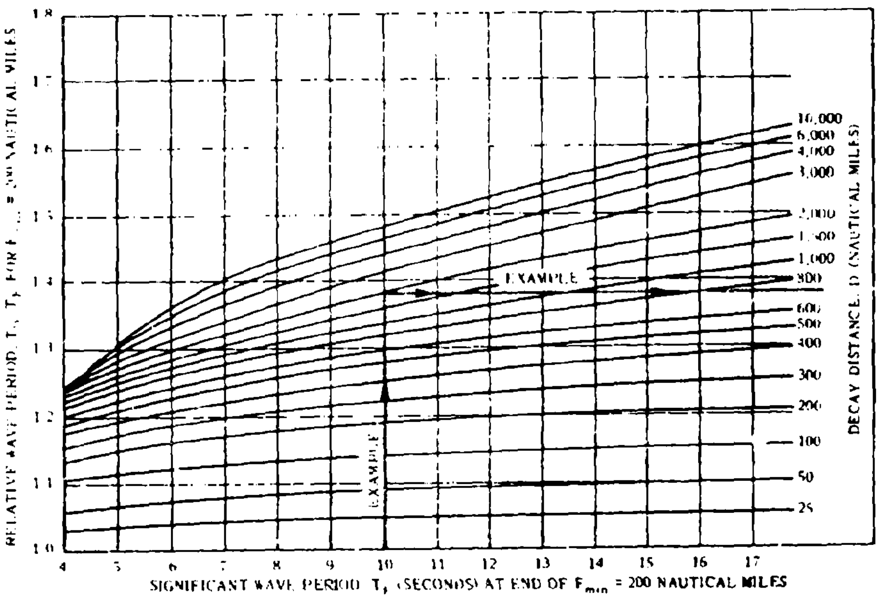
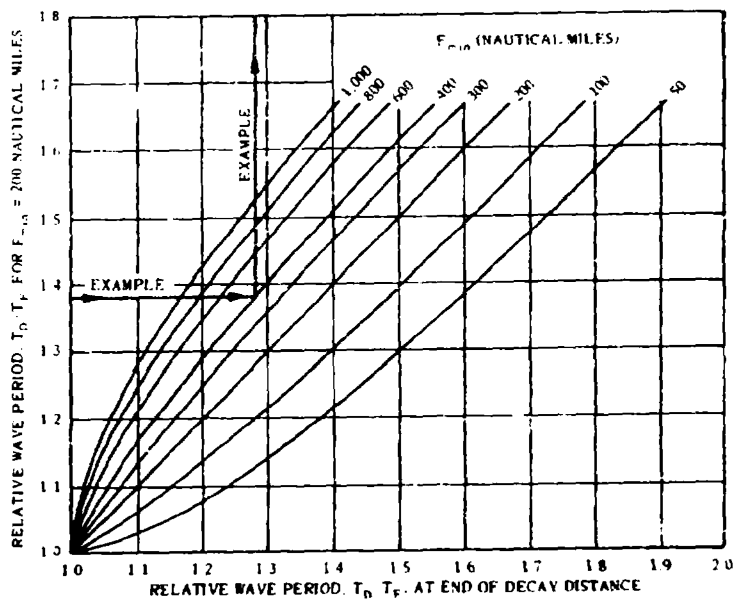


Figure B-2. Forecasting Curves for Wave Generation.



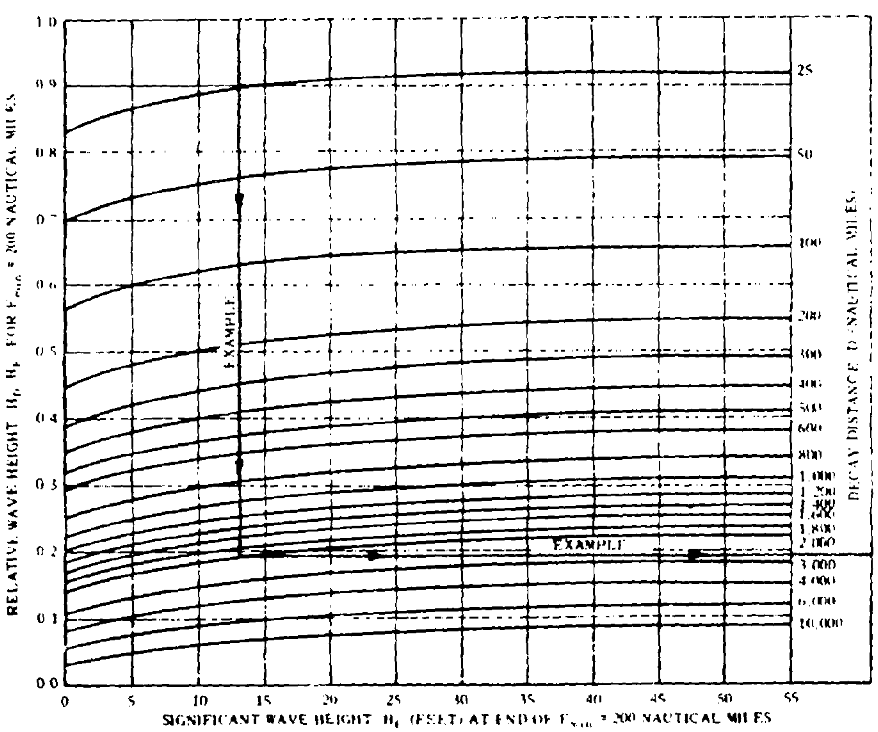


(a) RELATIVE INCREASE IN WAVE PERIOD T_D/T_F WITH RESPECT TO DECAY DISTANCE FOR VALUES OF T_F AT END OF F_{min} = 200 NAUTICAL MILES

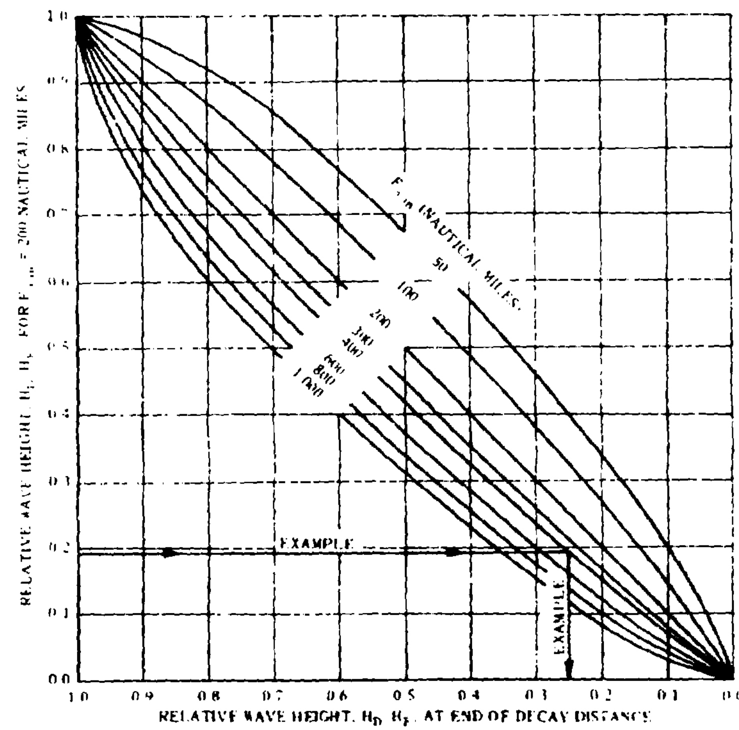
EXAMPLE: T_F = 10 SECONDS, D = 2,000 NAUTICAL MILES,
F_{min} = 400 NAUTICAL MILES; T_D/T_F = 1.28,
T_D = 1.28 X 10 = 12.8 SECONDS

(b) RELATIONSHIP BETWEEN THE RELATIVE WAVE PERIOD, T_D/T_F, OF F_{min} = 200 NAUTICAL MILES AND F_{min} = 50 TO 1,000 NAUTICAL MILES

Figure B-3. Wave Decay Graphs.



(c) RELATIVE DECREASE OF WAVE HEIGHT, H_D/H_F, WITH RESPECT TO DECAY DISTANCE FOR VALUES OF H_F AT END OF F_{min} = 200 NAUTICAL MILES



(d) RELATIONSHIP BETWEEN THE RELATIVE WAVE HEIGHT, H_D/H_F, OF F_{min} = 200 NAUTICAL MILES AND F_{min} = 50 TO 1,000 NAUTICAL MILES

EXAMPLE: H_F = 13 FEET; D = 2,000 NAUTICAL MILES,
F_m = 400 NAUTICAL MILES, H_D/H_F = 0.251
H_D = 13 X 0.251 = 3.26 FEET

Figure B-3. Concluded.

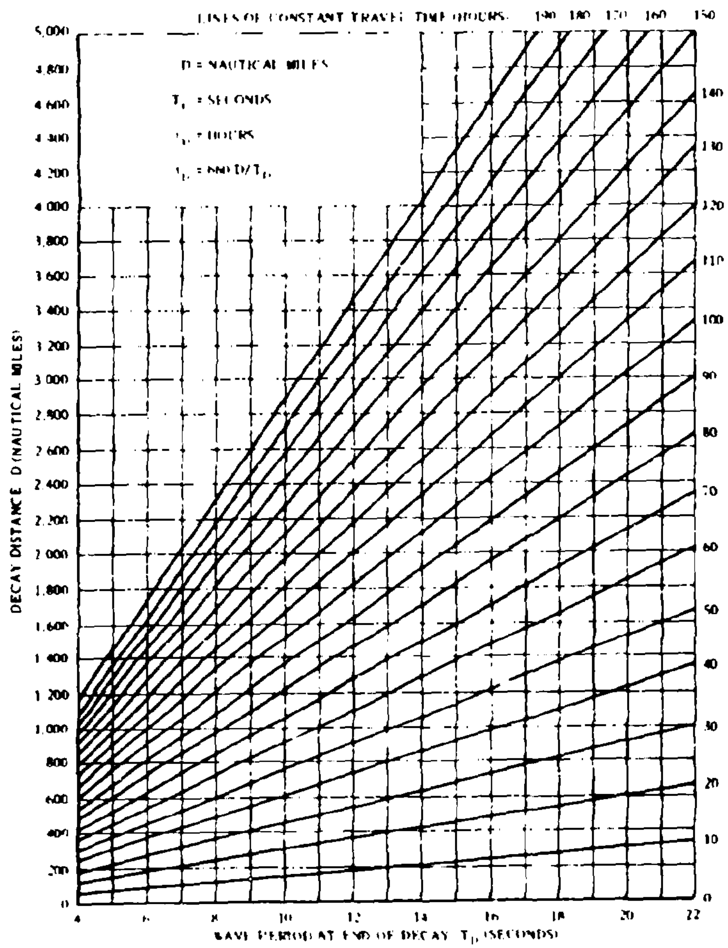


Figure B-4. Travel Time of Swell Based on $t_D = D/C_g$.

2. If sea-state observations are nonexistent, scanty, or unreliable, values of waveheight and period can be determined from knowledge of the wind field. Use values of wind velocity (U), fetch distance (F), and minimum duration (light solid lines); enter the value from figure B-2 to determine H_F and T_F. Fetch distance is defined as the continuous area of water over which the wind blows in essentially a constant direction. Duration is the length of time the wind blows in essentially the same direction over the fetch. Use the fetch distance (F) for F_{min} in figure B-3 and the determined values of H_F and T_F; proceed as in 1b and 1c above.

3. The direction of wave travel ($d_w d_w$) can be determined from observational data or from the direction of wind flow over the fetch area. When there are small intense storms where the wind direction is not essentially constant over the wave-generating area, use figure B-5 for determination of $d_w d_w$.

4. Figure B-6 is useful for determining limiting angles for waves which could affect Point Mugu area beaches and also for expected wave periods at different times during the year.

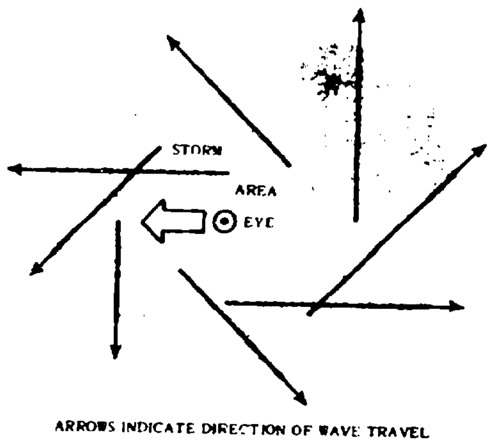


Figure B-5. Relative Direction of Swell Emerging From Tropical Storm Traveling at Speed of 10 Knots.

SURF FORECASTING PROCEDURES
(To be used with worksheet)

1. Determine the deepwater swell height (H_o), the deepwater wave period approaching the beach (T_o), and the direction of swell travel ($d_w d_w$).

2. Use the values of $d_w d_w$ in table B-1 to determine the angle the deepwater waves make with the depth contours (a_o).

3. Use the values of T_o and H_o in table B-2 to obtain the breaking depth uncorrected for refraction divided by the deepwater wavelength $[d_{b(u)}/L_o]$.

4. Use the values of a_o and $[d_{b(u)}/L_o]$ in figure B-7 to obtain the refraction factor (K_d) from the dashed lines and the breaker angle (a_b) from the solid lines.

5. Multiply: $H_o \times K_d = H_o'$ to obtain the swell height corrected for refraction (H_o').

   NOTE: H_o' may also be obtained from the wave refraction diagrams available to the Forecast Duty Officer. The diagrams indicate the ratio of shallow water swell height to deep water swell height, H_o'/H_o. The shallow water swell height after refraction (H_o') is obtained by multiplying the deep water swell height (H_o) by the value indicated on the refraction chart for the direction and period corresponding to the deep water swell conditions.

6. Use the values of H_o' and T_o to obtain the deepwater wave steepness index (H_o'/T_o^2) from figure B-8.

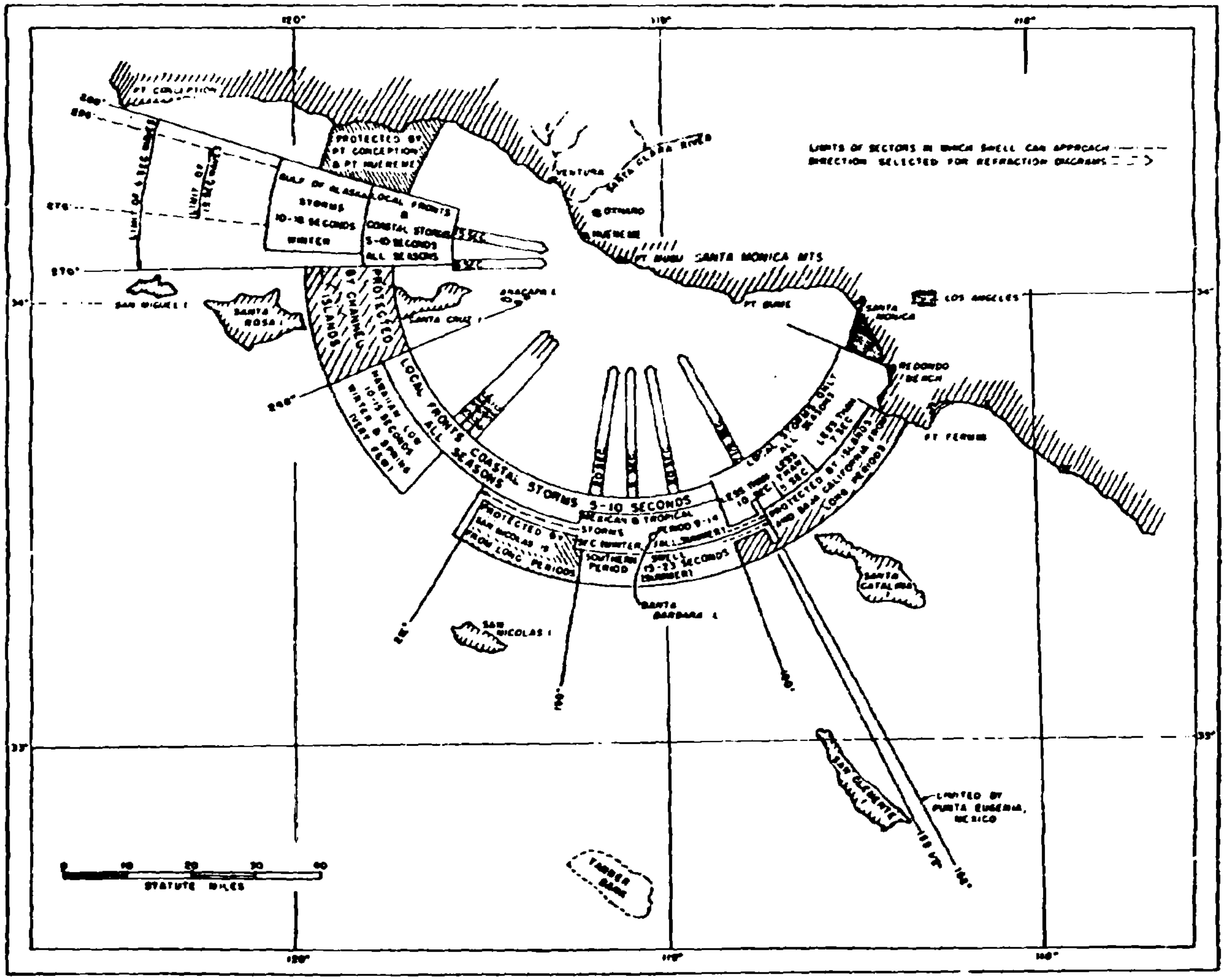


Figure B-6. Diagramatic Illustration of Waves Approaching Mugu Lagoon.

Table B-1. Conversion of Deepwater Wave Direction ($d_w d_w$) to Angle With Bottom Contours (a_o)

Mugu Pier Beach $d_w d_w$	Laguna Point Beach $d_w d_w$	Middle Point Beach $d_w d_w$	Ormond Beach $d_w d_w$	NCEL Beach $d_w d_w$	Silver Strand Beach $d_w d_w$	Hollywood Beach $d_w d_w$	All Beaches a_o
180	140	210	220	190	240	250	0
190/170	150/130	220/200	230/210	200/180	250/230	260/240	10
200/160	160/120	230/190	240/200	210/170	260/220	270/230	20
210/150	170/110	240/180	250/190	220/160	270/210	280/220	30
220/140	180/100	250/170	260/180	230/150	280/200	290/210	40
230/130	190/090	260/160	270/170	240/140	290/190	300/200	50
240/120	200/080	270/150	280/160	250/130	300/180	310/190	60
250/110	210/070	280/140	290/150	260/120	310/170	320/180	70
260/100	220/060	290/130	300/140	270/110	320/160	330/170	80
270/090	230/050	300/120	310/130	280/100	330/150	340/160	90

Table B-2. Breaking Depth, Uncorrected for Refraction, Divided by Deepwater

Wavelength $\left[\frac{d_{b(u)}}{L_o}\right]$

H_o \ T_o	3	4	5	6	7	8	9	10	11	12	13
3		0.049	0.035	0.026	0.019						
4		0.066	0.043	0.032	0.025	0.021					
5		0.086	0.054	0.038	0.030	0.025	0.021				
6		0.107	0.064	0.045	0.035	0.028	0.024	0.021			
7		0.133	0.076	0.051	0.039	0.031	0.026	0.023	0.020		
8		0.158	0.088	0.059	0.044	0.035	0.029	0.025	0.022	0.020	
9			0.103	0.067	0.048	0.038	0.032	0.027	0.024	0.022	0.020
10				0.075	0.054	0.042	0.034	0.029	0.025	0.023	0.021
11				0.084	0.059	0.045	0.035	0.031	0.027	0.025	0.022
12				0.093	0.065	0.049	0.039	0.033	0.029	0.026	0.024
13				0.103	0.070	0.053	0.043	0.036	0.031	0.028	0.024

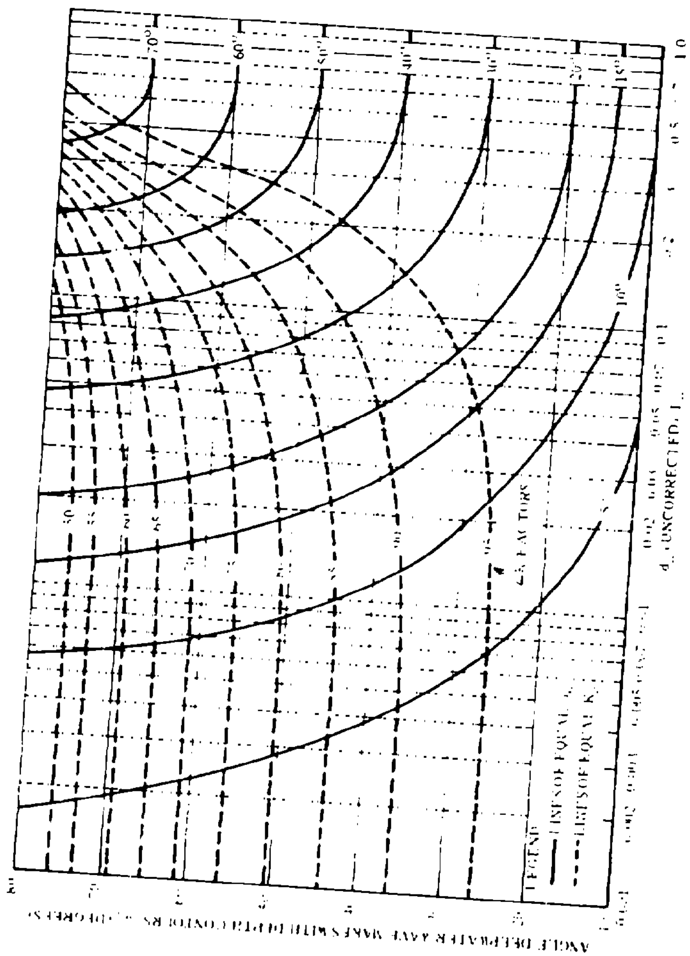


Figure B-7. Graph for Determining Coefficient of Refraction and Breaker Angle.

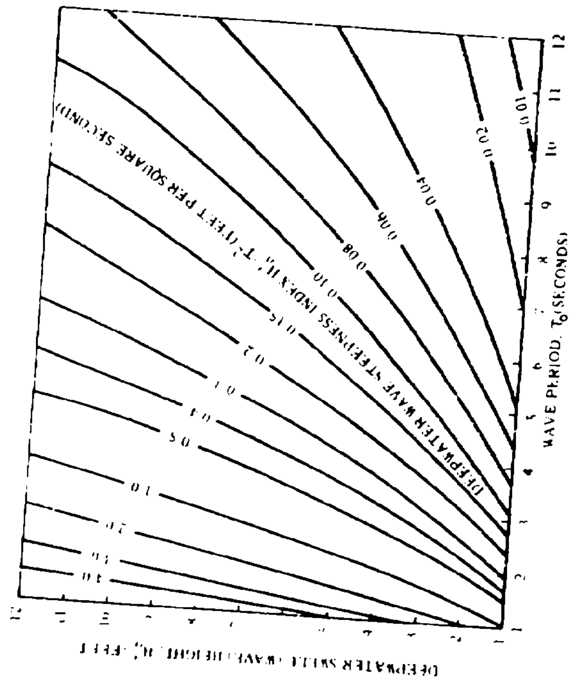


Figure B-8. Graph for Determining Deepwater Wave Steepness Index.

7. Obtain breaker height index (H_b/H_0') from figure B-9. Use a beach slope of 1:10 for Laguna Point and Mugu Pier beaches and a slope of 1:20 for other beaches.

8. Mulitply $H_0' \times H_b/H_0' = H_b$ to determine the significant breaker height.

9. Obtain the type of breakers from figure B-10; use H_0'/T_0^2 and beach slopes indicated in step 7 above. Normally more than one type of breaker will occur; therefore, an estimate of the percent of each type forecast should be made. The following rules should be helpful in determining the proper percentage of breaker types:

   a. The larger the value H_0'/T_0^2, the larger the percent of spilling breakers.

   b. With low values of H_0'/T_0^2 the breakers are plunging or surging.

   c. With steeper beach slopes (1:10 is steeper than 1:20) the percent of spilling breakers is less.

   d. Offshore winds may change spilling breakers into plunging breakers.

   e. Onshore winds may change plunging breakers into spilling breakers.

10. Obtain the breaker depth index (d_b/H_0') from figure B-11/

11. Multiply $H_0' \times d_b/H_0' = d_b$ to determine the depth at which the waves start breaking.

12. Obtain the width of the surf zone in yards (W_y) and the width of the surf zone in feet (W_f) from figure B-12.

13. Use values of d_b and T_o from figure B-13 to obtain the breaker wavelength (L_b).

14. Divide: W_f/L_b to obtain the number of lines of surf.

SURF FORECAST WORKSHEET

Forecast Area								
Step	Value	Source						
1(a)	H_o	Figure B–3						
1(b)	T_o	Figure B–3						
1(c)	$d_w d_w$	Observations or figure B–5						
2	a_c	Table B–1						
3	$d_{b(u)}/L_o$	Table B–2						
4(a)	K_d	Figure B–7						
4(b)	a_b	Figure B–7						
5	H_o'	$H_o \times K_d$						
6	H_o'/T_o^2	Figure B–8						
7	H_b/H_o'	Figure B–9						
8	H_b	$H_o' \times H_b/H_o'$						
9	Breaker type	Figure B–10						
10	d_b/H_o'	Figure B–11						
11	d_b	$H_o' \times d_b/H_o'$						
12(a)	W_v	Figure B–12						
12(b)	W_f	Figure B–13						
13	L_b	Figure B–14						
14	Lines of surf	W_f/L_b						

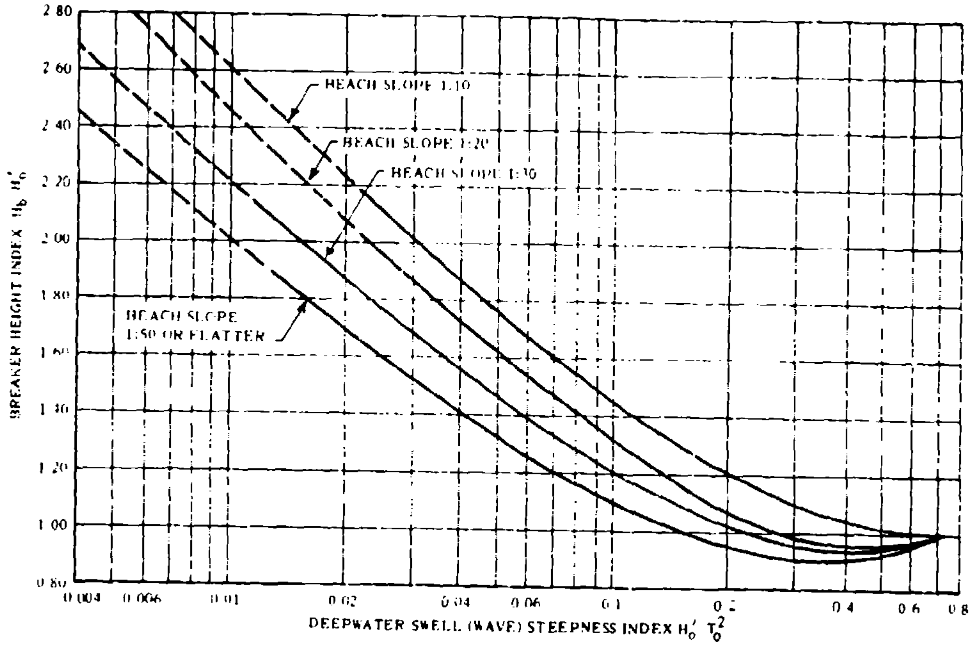


Figure B-9. Graph for Determining Breaker Height Index.

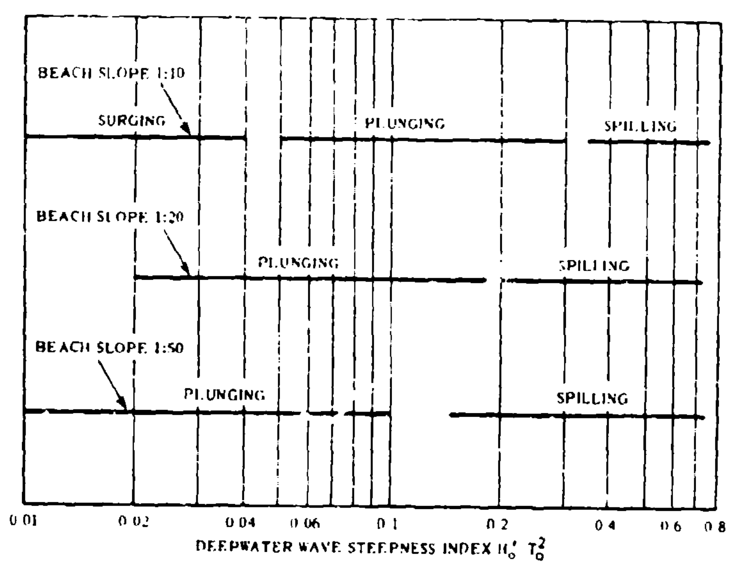


Figure B-10. Graph for Determining Breaker Type.

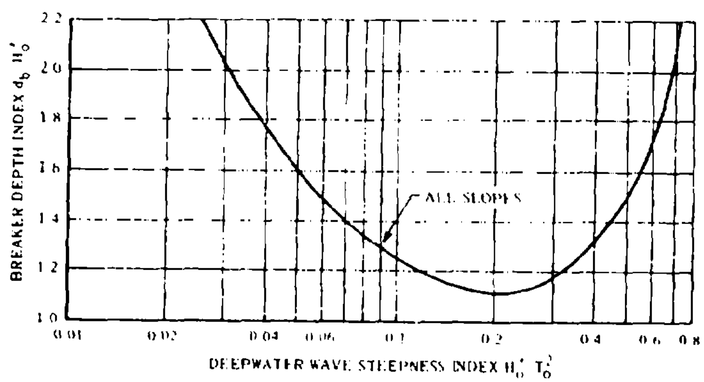


Figure B-11. Graph for Determining Breaker Depth Index.

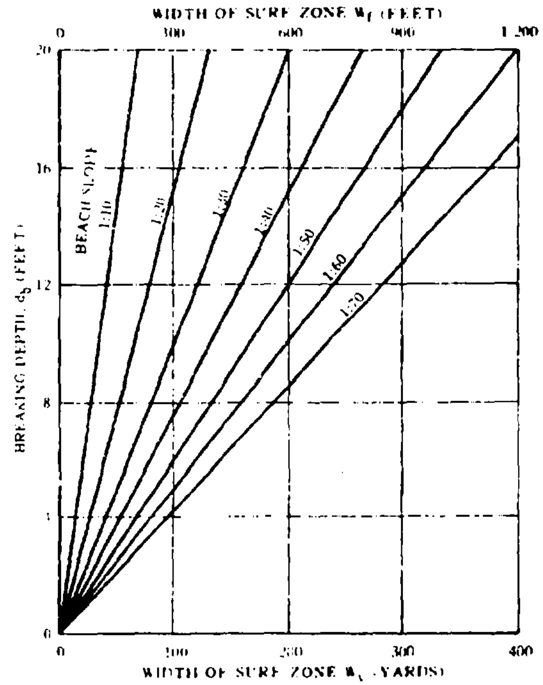


Figure B-12. Graph for Determining Width of Surf Zone.

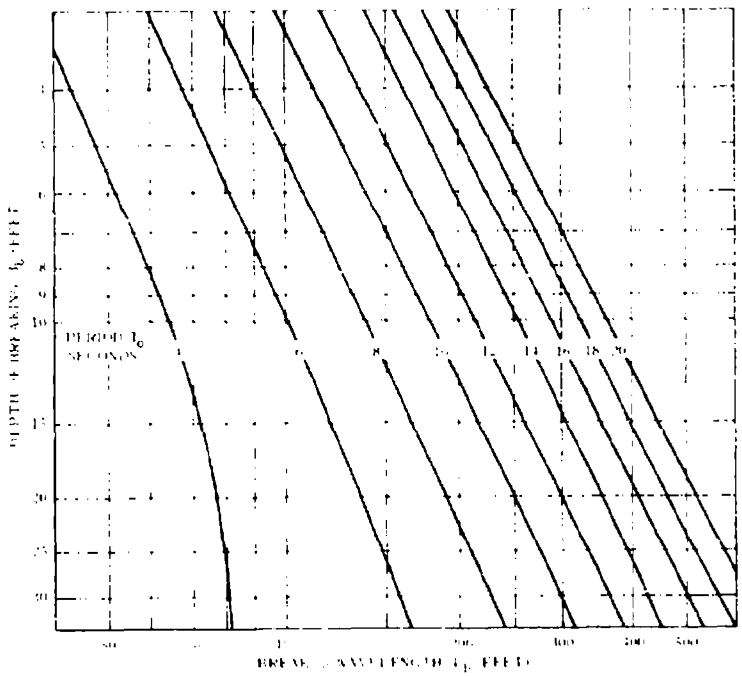


Figure B-13. Graph for Determining Breaker Wavelength.

DETERMINATION OF SPEED OF LONGSHORE OR LITTORAL CURRENT

Longshore or littoral currents are shallow water currents flowing parallel to shorelines. These currents are most often generated by waves breaking at an angle to the beach. The transport of sand along a beach is generally attributed to such currents. The speed of longshore currents can be determined from figure B-14 if the deepwater wave period, T_o, the significant breaker height, H_b, the angle of wave approach, a_o, and the beach slope are known. The example in figure B-14 illustrates the use of the nomogram.

The littoral current can also be easily determined by measuring the longshore movement of a low-freeboard floating object. Note the distance in feet which the object traverses in 1 minute, move the decimal point two places to the left, and the resulting number is the littoral current in knots. As an example, if a woodchip moves 90 feet in 1 minute, the littoral current is 0.90 knots.

DETERMINATION OF WIND DRIFT CURRENTS

Figure B-15 is a nomograph to be used in determining the speed of wind drift currents. The wind duration, wind velocity, and the fetch must be known.

COMPUTERIZED FORECASTING OF BREAKER HEIGHTS ON POINT MUGU BEACHES

Description

This program is a computerized version of the manual objective method of forecasting local surf conditions which has been used at Point Mugu in recent years and which was described earlier in this appendix.

Example

T_o = 8.1

H_b = 5.75

Slope = 1:60

a_b = 24°

(1.) Enter graph with T_o and H_b. Locate intersection of line between T_o and H_b and the left diagonal.

(2.) Construct a line from beach slope through intersection, located above, to breaker height line and mark this intersection.

(3.) Construct a line from a_b to horizontal breaker height line at top of figure and mark intersection on right diagonal.

(4.) Construct line from mark located in (2) and intersection located in (3). Continue line to get correct speed: V = 3.5 knots.

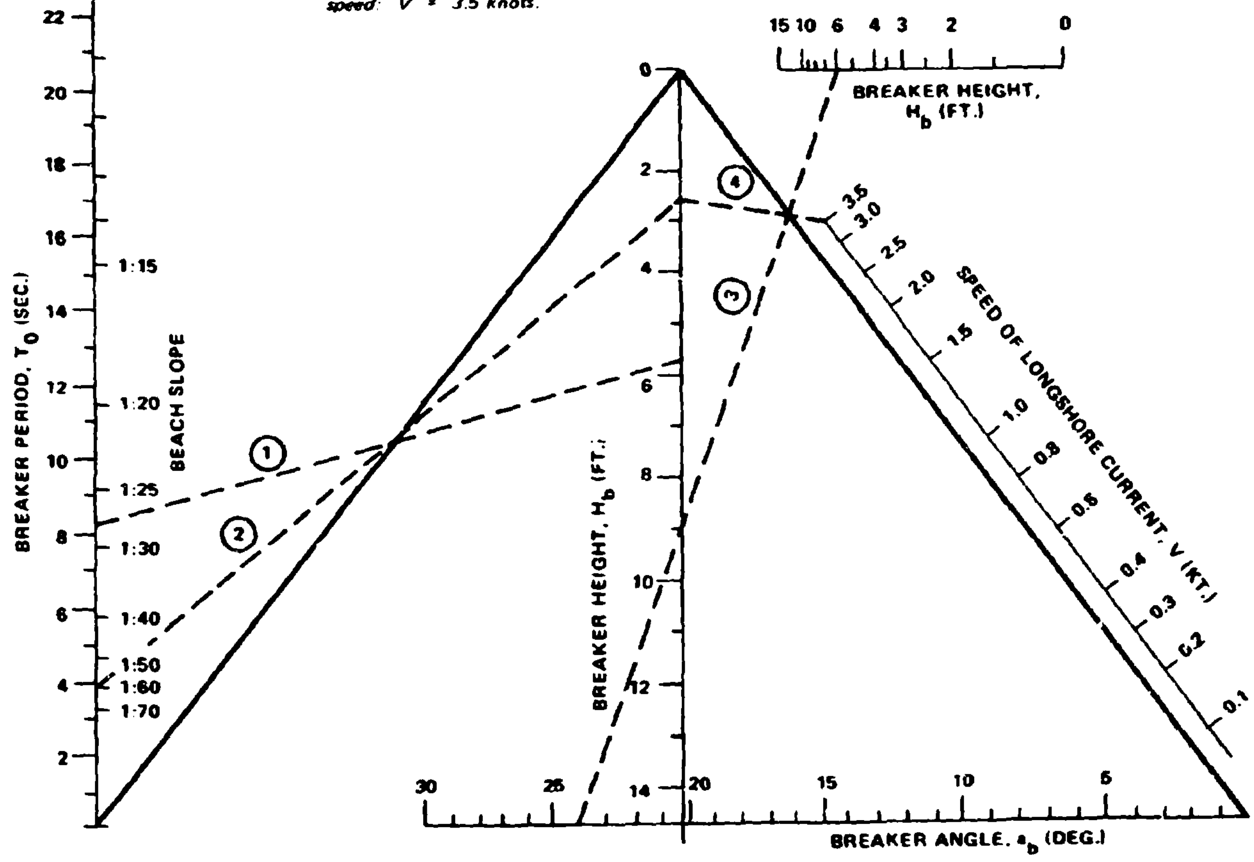
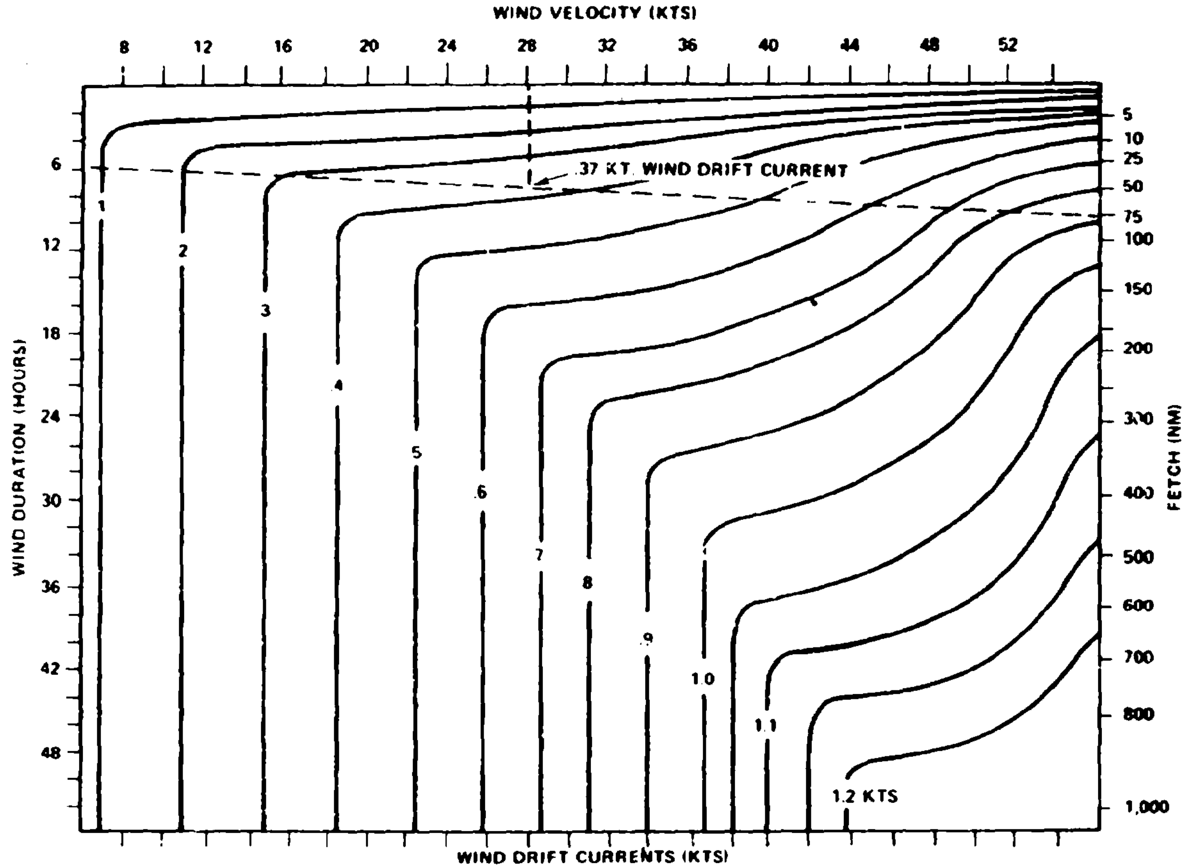


Figure B-14. Nomogram for Determining Speed of Longshore Current.



These wind drift current forecasting curves are taken from "Ocean Thermal Structure Forecasting", by R. W. James ($1.50 from Supt. of Docs., U.S. Gvt. Print. Office, Wash., D.C. 30402). Duration is to the left, wind velocity on top, and fetch to the right. The steady state wind drift current is shown by the straight lines. If you are calculating the wind driven surface current with changing wind conditions (or if the wind is imposed on an existing current from whatever source) you must first break the fetch down into a simple series of stepped velocity changes. At each new wind velocity you must back-figure duration at the new wind velocity necessary to produce the current prevailing at the start of the new wind velocity. Then add the equivalent duration to the new-velocity duration, and then apply this time factor in the nomograph to find the final wind drift speed. The illustrated example (blue) supposes a wind velocity of 28 kts over a fetch of 75 miles for a duration of 6 hours producing a wind drift current of 0.37 kts.

Figure B-15. Nomogram for Determining Wind Drift Currents.

Essentially, the computerized version is a compilation of several tables, graphs and equations from various sources itemized on the Reference Lists which involve meteorological conditions, statistical considerations, and existing sea conditions as objective aids. These are used first to estimate or forecast the deep-water variables--swell height, wave period and direction of travel--which in turn provide the basis for the final forecast of breaker height and angle for three (3) local beaches. The method incorporates the shadow effects of Baja California and of the several offshore islands. It assumes that the local beaches have straight and parallel contours so that there is no convergence or divergence due to curved contours.

Input

There are two options for using this program, a general one for swell generated by extratropical or weak tropical storms, and a specialized one for swell generated by stronger tropical storms.

1. For the general case, the following are required inputs for the program:

   Name of storm or designation of fetch area
   Initial date and time
   Swell height at the end of the fetch
   Swell period at the end of the fetch
   Length of minimum fetch
   Distance of end of fetch from Point Mugu
   Direction of source from Point Mugu

2. For the case of a tropical storm with winds exceeding 40 knots, the specialized method is based on reference 90. This assumes that wave height and period are fairly constant with distance from the storm center out to a point where the windspeed drops to 40 knots, and that such storms travel at an average speed of 10 knots. The required inputs are:

   Name of storm
   Initial date and time
   Direction of the storm from Point Mugu
   Direction towards which the storm is moving
   Distance of the storm from Point Mugu
   Length of minimum fetch

Output

For both input options, the program output is the same:

1. A statement of whether Point Mugu will be in a shadow zone from an island or other land mass.

Name of storm
Initial date and time
Swell travel time to Point Mugu
Expected arrival date and time
Deepwater swell height and period near the coast
Breaker height and breaker angle for:

Mugu pier
Laguna Point
Middle Point

<u>Verification</u>

A preliminary evaluation of the results obtained with this program was conducted for the period 24 August through 8 September 1968, during which surf in the Point Mugu area reflected the effects of four tropical storms in the eastern North Pacific. During this period, duty forecasters routinely completed Breakers Worksheets (sample attached) based on

BREAKERS WORKSHEET

1-12	13-24	24-27	28-30	31-34	35-38	39-41	42-43	45

1-12 IDENTIFICATION (12 spaces)
13-24 DATE TIME (12 spaces)
25-27 DIRECTION OF STROM FROM POINT MUGU IN WHOLE DEGREES
28-30 DIRECTION OF STORM TRAVEL IN WHOLE DEGREES (BLANK FOR OPTION B)
31-34 DISTANCE OF STORM FROM POINT MUGU IN WHOLE MILES (4 spaces)
35-38 LENGTH OF MINIMUM FETCH (USE 200 FOR AVERAGE SIZE STORM, OPTION A) IN WHOLE MILES (4 spaces)
39-41 SWELL HEIGHT AT END OF FETCH IN WHOLE FEET (BLANK FOR OPTION A) (3 spaces)
41-44 SWELL PERIOD AT END OF FETCH IN WHOLE SECONDS (BLANK FOR OPTION A) (3 spaces)
45 OPTION INDICATOR 1 FOR OPTION A
2 FOR OPTION B

OPTION A

EX. WARNING RECEIVED FOR TROPICAL STROM CELESTE FOR 24 JULY AT 0600Z. STORM 200 DEGREES FROM POINT MUGU TRAVELING TOWARD 300 DEGREES AT A DISTANCE OF 1,200 MILES FROM POINT MUGU. STORM HAS AT LEAST 40-KNOT WINDS AND TRAVELING AT ABOUT 10 KNOTS.

CELESTE	24 JUL 0600Z	200	300	1200	0200			1
1-12	13-24	25-27	28-30	31-34	35-38	39-41	42-44	45

OPTION B

EX LOW 250 DEGREES FROM POINT MUGU GENERATING SWELL OF 12 FEET WITH A PERIOD 8 SECONDS. FETCH 800 MILES LONG, END OF FETCH 900 MILES FROM POINT MUGU.

LOW NO. 4	24 JUL 0600Z	250		0900	0800	012	008	2
1-12	13-24	25-27	28-30	31-34	35-38	39-41	42-44	45

tropical storm position reports and warnings received from FLEWEACEN Alameda. In this way, computerized surf forecasts were prepared on 14 separate days, and were verified against subjective observations made routinely at one of the three beach locations involved. Principal conclusions of the results are as follows:

1. In all but one case, an increase or decrease in observed breaker height was accompanied by a corresponding increase or decrease in the forecast breaker height.

2. The forecasts gave from 2 to 4 days warning on high breakers.

3. When the forecast values are large they compare better with the maximum observed breaker heights than with the significant heights.

4. The method tends to overforecast breakers resulting from distant storms, presumably due to an equation which exaggerates breaker heights under conditions of low waves and long periods. (Empirical corrections have been added to the programmed equations to compensate for items 3 and 4.)

5. When Point Mugu is in the shadow of offshore islands, the storm will nevertheless produce swells which affect local beaches. When Point Mugu is in the shadow of Baja California, however, noticeable swells are not produced.

6. When more than one storm affects Point Mugu on a given day, the resultant breaker heights are not simply additive. Present procedure is to concentrate on the individual storm that gives the highest forecast breakers.

The following page is a copy of a Surf Observation Worksheet as operationally completed for an actual day at Point Mugu.

POINT MUGU SURF OBSERVATIONAL WORKSHEET

SURF OBSERVATION OF POINT MUGU FOR 13 (DATE) 1130 (TIME) Dec (MONTH) 1969 (YEAR)

	OBSERVATION POINTS	
	GROIN SITE - A	BUILDING 761 - B
A. SIGNIFICANT BREAKER (Height to nearest one-half foot)	8.0	8.0
B. MAXIMUM BREAKER (Height to nearest one-half foot)	12.0	10.0
C. BREAKER PERIOD (To the nearest 0.5 second)	10.0	14.0
D. PERCENT PLUNGING AND PERCENT SPILLING	100 % PLUNGING -- % SPILLING	100 % PLUNGING -- % SPILLING
E. ACUTE ANGLE FROM RIGHT OR LEFT THAT THE BREAKER MAKES WITH THE OBSERVER	020 DEGREES FROM Right	030 DEGREES FROM Right
F. LITTORAL CURRENT VELOCITY (To nearest 0.1 knot toward right or left direction)	1.0 KNOTS TOWARD THE Right DIRECTION	____ KNOTS TOWARD THE ____ DIRECTION
G. REMARKS (fog, unusual weather, unusual wind, water temperature, etc.)	SWT 60	

Cook BG3
OBSERVERS NAME AND RATE

TSUNAMIS

Tsunami is the correct name for seismic sea-waves which are generated due to earthquakes and volcanic eruptions. They have been popularly referred to as "tidal waves." The best descriptions of the effects of tsunamis and the Government's seismic seawave warning system is described in a booklet published by the Coast and Geodetic Survey entitled "Tsunami," reference 95.

The following paragraphs which refer to coastal California are copied below from this reference:

> Tsunami bulletins and warnings for California, Oregon, and Washington are sent via FAA or the Defense Communications System to Department of Army Office of Civil Defense (DOAOCD), 28th Warning Center, Hamilton Air Force Base, California. From this center, messages are disseminated to established points within each of the three states, via the National Warning System (NAWAS).
>
> In California, tsunami messages are received by the California Disaster Office (CDO), Sacramento. If this state warning point is inoperative, tsunami messages are routed to the California Highway Patrol, Sacramento. The state Warning Control Officer has the task of evaluating the significance of tsunami messages, and taking necessary alerting action in response to them.

The PMR Weather Center does not have any forecasting responsibilities with respect to tsunamis. All warnings and forecasts will be issued by the Seismic Sea Wave Warning Service of the Coast and Geodetic Survey.

FACTORS WHICH PRODUCE PSEUDO-CATALINA EDDIES

A surface pressure at San Nicolas Island more than 1 millibar lower than at Los Angeles is sometimes considered an indicator of an impending Catalina Eddy. However, many times when this pressure difference is observed, a true Catalina Eddy does not actually exist (reference 29). This is in spite of the fact that when local forecasters analyze the pressure and wind distribution over southern California, pressures at both San Nicolas and Santa Catalina Islands are quite often lower than along the coast. Also, San Nicolas will report northwest winds at the same time that Catalina reports west-southwest winds. Therefore, the forecaster would be led to analyze a small closed low near these two islands.

The reasons for this error are twofold: (1) because both San Nicolas and Catalina Island weather stations are located considerably higher than sea level, standard procedures are used to reduce the station pressures to sea level. However, if there is a low strong inversion--which there frequently is--with base below the altitude of the island weather station, the sea level pressure computed for the island station will be lower than the actual sea level pressure measured at a beach weather station; and (2) there is a probable bias in Catalina surface winds toward west-southwest.

These two factors lend to a built-in tendency for appearance of pseudo Catalina Eddies on weather charts. Because of this, an analyzed Catalina Eddy should not be used to explain unexpected changes in Point Mugu weather.

Reduction of Pressure to Sea Level

The routine calculation of sea level pressure involves an extrapolation of observed station pressure down through a hypothetical air column which extends from station altitude to sea level. In official procedures it is assumed that the nonexistent distributions of temperature and humidity in the hypothetical air column are approximated by standard lapse rates. In coastal areas with sharply varying topography and mountainous islands, the amount of extrapolation is in direct relation to the depth of the hypothetical air column: the deeper the column, the greater the extrapolation. Computed sea level pressures at several adjacent stations will be comparable only to the extent that the actual atmospheric lapse rates in a given case conform to the assumed standard lapse rates.

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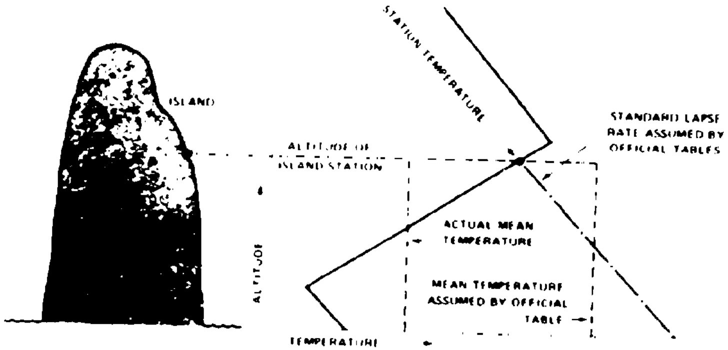
Effect of Local Inversion Conditions

If the actual atmosphere departs significantly from standard--as it typically does in coastal southern California with pronounced low level temperature inversions--reported sea level pressures from weather stations actually located near sea level such as Point Mugu will not be comparable with those reported from high-altitude stations (San Nicolas and Catalina Islands). As shown in figure C-1, whenever the inversion base is located below the altitude of an Island station, the mean virtual temperature assumed for the hypothetical air column in official computation tables will be warmer than the mean virtual temperature of a corresponding column of air in the actual



LOW LEVEL TEMPERATURE INVERSION IS BELOW ALTITUDE OF ISLAND STATION (FOR SIMPLICITY NO VIRTUAL TEMPERATURES ARE SHOWN)

Figure C-1. Source of Error in Reduction to Sea Level Pressure. (From reference 29.)

atmosphere surrounding the island. The hypothetical column beneath the station will thus be lighter than the colder column of actual air nearby. Therefore the sea level pressure extrapolated through the hypothetical column will be lower than the real sea level pressure measured at a ship offshore or at a beach station.

Figure C-2 illustrates the magnitude of this effect at San Nicolas. The error in computed sea level pressure is shown as a function of the station temperature and of the error in assumed mean virtual temperature of the hypothetical air column beneath the station. The mean virtual temperature can be estimated by the strength of the temperature inversion below the San Nicolas station elevation which is 507 feet MSL.

In a typical subsidence inversion situation, humidity departures from standard may produce a similar effect, depending on the height of the moist layer relative to the station. If the top of the moist layer is relatively low, the standard humidity lapse rate assumed for the hypothetical air column will be more moist and therefore lighter than the very dry inversion layer in the column of actual air nearby, so again the computed sea level pressure for the island station will be lower than the actual sea level pressure. Since wide variations of humidity distribution through the marine layer are common, it is difficult to generalize as to the probable magnitude of this humidity effect.

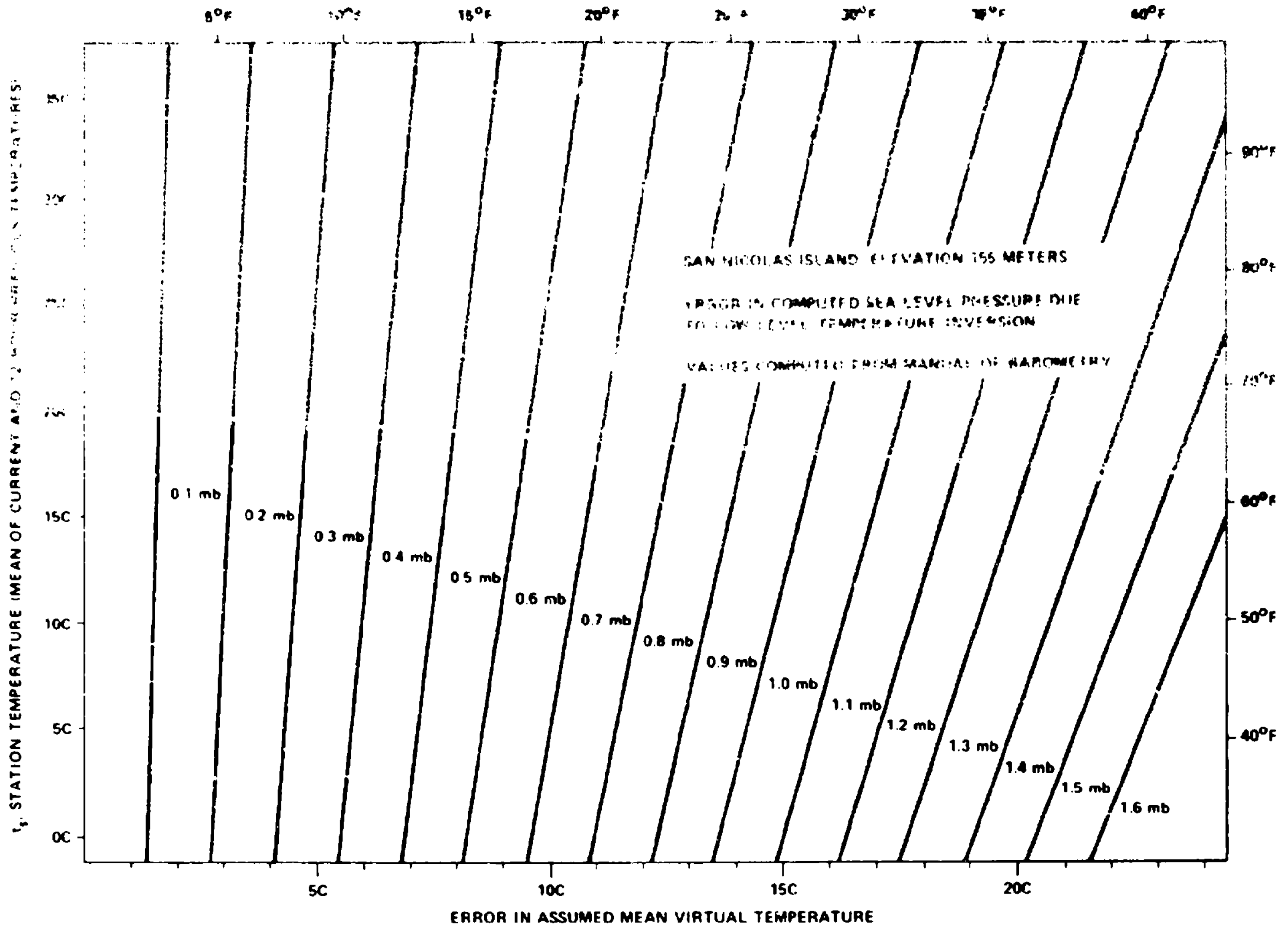


Figure C-2. Numerical Error in Millibars in Reduction to Sea Level Pressure; San Nicolas Island. (From reference 29.)

Synoptic Consequences

Reported pressures from other Channel Island stations are similarly affected by low level temperature inversions. Resulting pressure errors for various station elevations are graphed in figure C-3, where plotted errors represent mean values for station temperatures in the range 40° to 90°F. It can be seen that Catalina pressures may be 1 or 2 mb low under typical summertime inversion conditions.

Pressure errors of the magnitude indicated by figure C-3 are not significant for large-area synoptic analyses, such as national facsimile products, on which isobar intervals amount to several millibars and which necessarily involve smoothing of fine details. Such comparatively small errors, however, can be of considerable significance for locally-produced mesocale analyses, where every minute amount of data are plotted and isobars are analyzed at 1- or 2-millibar intervals to delineate minor circulation features.

Pseudo West-Southwest Winds at Santa Catalina Island

An additional factor of significance for mesoscale analyses of the Channel Island area is a probable bias in Catalina surface winds toward west-southwest. The airport weather station at Catalina is located at an elevation of 1,568 feet on what amounts to a narrow saddle between nearby peaks of 2,125 and 1,804 feet. These peaks, which shield the island from west-southwest winds, are at the head of Cottonwood Canyon that drops rapidly toward west-southwest to sea level. If the prevailing light winds are northwest, Catalina gets west-southwest winds blowing up the canyon. Climatological verification of this suspected bias is not readily possible because detailed summaries of wind frequency distributions for the Catalina airport are not available.

When the wind is west-southwest at Catalina but west-northwest at San Nicolas and elsewhere off the coast, the usual analysis is a pronounced trough or a weak closed low near the islands. This is typically explained by the analyst as a weak Catalina Eddy, not considered strong enough to affect coastal weather (but always handily available as a hindcast explanation for unexpected stratus). Occasionally, a forecaster may interpret such a feature as initial evidence of the incipient formation of a strong Catalina Eddy, and mistakenly forecast the onset of heavy coastal stratus.

The following conclusions and suggestions are given to aid the forecaster in analysis of PMR micro charts:

1. Reported sea level pressures from Channel Island stations located above or within a temperature inversion will be erroneously low. An approximate pressure correction can be determined from figure C-1 by estimating a temperature profile from sea level to station elevation on the basis

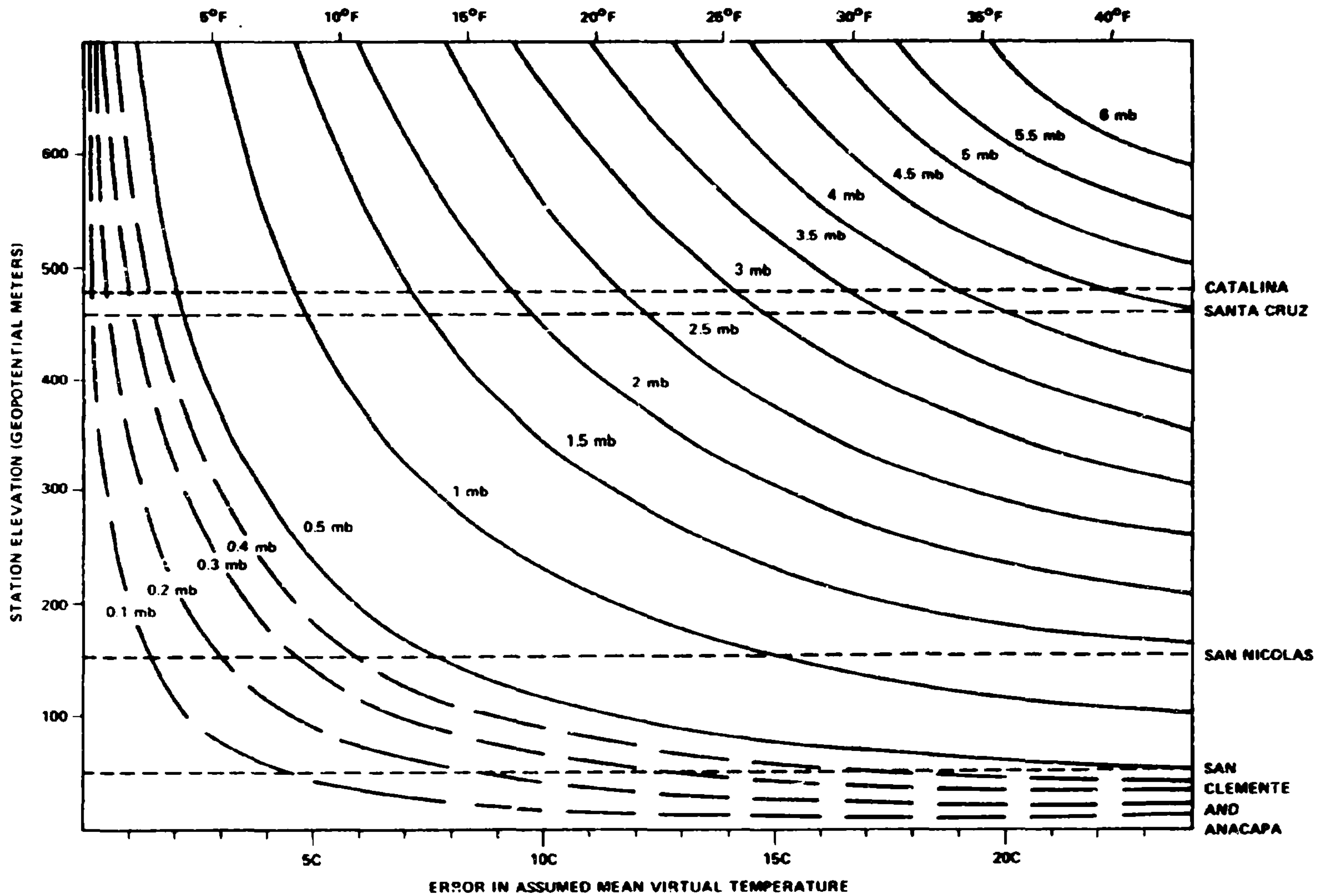


Figure C-3. Numerical Error in Millibars in Reduction to Sea Level Pressure; Other Channel Islands. (From reference 29.)

of a nearby coastal sounding from Point Mugu. Los Angeles, San Diego, or Vandenberg AFB. To use figure C-2, the mean virtual temperature error may be crudely approximated by the strength of the temperature inversion:

a. If the temperature inversion lies entirely below station elevation, use the temperature difference between top and base of the inversion.

b. If the inversion lies only partly below station elevation (the station is within the inversion layer), use the temperature difference between the station and the base of the inversion.

2. In lieu of figure C-3, a rough rule of thumb to apply is that the sea level pressure at San Nicolas will be 1/3 mb low for every 5°C of inversion below the station; sea level pressure at Catalina will be 1 mb low for every 5°C of inversion below the station.

3. With prevailing light to moderate northwest or west-northwest flow over the area, the forecaster can expect the reported wind at Catalina airport to be west-southwest. Do not consider such a west-southwest wind to be indicative of true gradient flow direction when analyzing isobars.

4. Analyses of weak Catalina Eddies based primarily on uncorrected island pressures should be viewed with suspicion. Unless an associated cyclonic circulation can be substantiated by ship or aircraft reports or by obvious southerly flow at coastal stations, such eddies may well be pseudo. This does not mean, however, that all Catalina Eddies are pseudo. Subsynoptic-scale vortices or eddies frequently occur in the lee of southern California mountain ranges and downwind of the Channel Islands. That these can be associated with significant changes in coastal weather is well recognized, though the relationships are not well defined nor understood.

PMR WEATHER CENTER FORECAST VERIFICATION METHOD

The concept of forecast verification is a very important one in meteorology. Unless committed to a specific objective method, weather forecasters would not be able to evaluate their skill and might also tend to be biased favorably in reporting their own success.

At Point Mugu and throughout coastal southern California, forecast verification criteria must be even more stringent than at typical mid-latitude locations (reference 96) because the climate here is characterized by relatively weak and infrequent synoptic-scale weather changes. Annual and seasonal variations of most weather parameters are small, and climatology and persistence verify relatively well as forecasts. Because of these factors, the Point Mugu forecaster to demonstrate skill should produce better forecasts than those at mid-latitude stations.

On the other hand, local and mesoscale variations in southern California are often quite large and pre-

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dominate over the synoptic scale. Thus, conventional forecast methods based on large-scale synoptic analyses, prognoses, and theory are sometimes not applicable to local weather problems and in general are less successful here than they are at the mid-latitude continental stations. The Point Mugu forecaster must therefore rely heavily on tools developed from special local studies concerned with the Point Mugu atmosphere. The PMR forecaster is thus faced with the dilema that his forecasts must verify better than those elsewhere to demonstrate meaningful forecast skill while having to develop and apply his own non-routine forecast rules and techniques for the local area.

The PMR Weather Center's operational verification method developed by LCDR R. C. Corbeille and AGC H. O. Deloughery attempts to bridge the conflicting trends of synoptic inactivity and mesoscale and local activity of Point Mugu weather. The method derived (shown in table D-1) is intended to be fair to the forecaster and yet be both representative and realistic considering the normal and extreme variations in various weather parameters experienced at Point Mugu on an annual, seasonal, and daily basis.

When all of the forecast parameters verify within the appropriate limits, the forecaster is awarded 100 points for a perfect forecast. As the discrepancies between forecast and observed values increase and exceed the various tolerances, points are deducted so that a forecast poor in all respects can attain a justified value of zero.

Table D-1. Forecast Verification.

		WBAN 10 A/B entries (PST)	WBAN 10 A/B entries (PDT)
TODAY	0800 - 1959	0800 - 1959	0700 - 1859
TONIGHT	2000 - 0759	2000 - 0759	1900 - 0659
TOMORROW	0800 - 1959	0800 - 1959	0700 - 1859

NOTE: (PERFECT SCORE FOR EACH PERIOD • 100 Points)

LOWEST CEILING (15 Points)

Enter 2 digits for hundreds of feet; add 50 for cigs above 5,500 feet.

TOLERANCES

(Ceiling 0-1,500 ft.)		(1,600-5,500 ft.)		(6,000 ft. or more)	
Within 100 ft.	15 Points	Within 300 ft.	15 Points	Within 2,000 ft.	15 Points
200	13	500	13	3,000	13
300	11	700	11	4,000	11
400	8	900	8	5,000	8
500	5	1,100	5	6,000	5
More than 500	0	More than 1,100	0	More than 6,000	0

TIME OF STRATUS BREAK/FORM (10 Pts.)

Within 1 hr.	10 Points
2	8
3	6
4	4
More than 4 hrs	0

AVERAGE SKY COVER IN TENTHS (10 Pts.)

SKY	TENTHS	CODE	WITHIN	POINTS
CLR	0	0	0	10
MSTLY CLR	1 - 2	1	2	8
PTLY CLDY	3 - 5	4	3	6
MSTLY CLDY	6 - 8	7	4	4
CLDY	9 +	9	5+	0

(Stratus break-up is defined as time at which cloud amount goes to 0.5 or less for 2 hours or more; formation is defined as time at which cloud amount exceeds 0.5 for 2 hours or more. Consider stratus and sfc based fog only.)

VISIBILITY (15 Points)

TOLERANCES

0 - 3 Mile Range		VSBY 4 Miles or more	
Within 1/2	15 Points	Within 1	15 Points
1	12	2	12
1½	9	3	5
2	5	More than 3	0
More than 2	0		

TEMPERATURES (Max. & Min.)

TOLERANCES (10 Points)

Within 2 Degrees	10 Points
3	8
4	6
5	4
6	2
More than 6	0

SURFACE WIND

DIRECTION (10 Points)		AVERAGE SPEED (10 Points)		DURATION OF TIME (10 Points)	
Within 30 Deg.	10 Points	Within 2 Knots	10 Points	Within 1 hour	10 Points
40	8	3	8	2	8
50	6	4	6	3	6
60	4	5	4	4	4
More than 60	0	More than 5	0	More than 4	0

Where the double block is divided, each half block will count as 5 points.

PRECIPITATION (10 Points)

Within 0.1 inches	10 Pts.
0.2	8
0.3	6
0.4	4
More than 0.4	0

NOTES: Wind Direction can be considered VARIABLE if no direction prevails for 5 hours or more and/or Average Speed is less than 4 knots. TRACE (T) may be used to verify precipitation if no measurable amount is expected at the station. If words SCATTERED SHOWERS or DRIZZLE are used in the forecast, "T" must be used in Precip. verification. Any sighting of a rain shower in vicinity or a report by a reliable source that rain or drizzle has occurred will be sufficient to verify "T." A FIVE-POINT penalty will be assessed if "T" cannot be verified or if more than 0.01 inch of rain fall. 10 points will be awarded if "T" verifies.

If a Thunderstorm occurs at the station and has not been forecast, a FIVE-POINT penalty will be assessed.

Tomorrows minimums will be entered at the bottom of the rough draft of the forecast, e.g., Stratus 1000,

WND

06	03	04
07	08	08

PRECIP T.

The surface wind columns have been divided into half blocks to provide space to log 2 significant directions, speeds and duration of hours, when necessary.

e.g.

WIND DIRECTION

06	V	V
25	V	27

WIND SPEED

12	3	03
07		08

WIND DURATION

05	12	04
07		08

THE ROUGH DRAFT OF THE FORECAST WILL BE PLACED ON THE ASSISTANT PROJECT FORECASTER'S DESK, WHO WILL RECORD AND VERIFY THE FORECAST AS AN UNBIASED INDIVIDUAL.

Prepared by: LCDR R. C. Corbeille and AGC H. O. Deloughery - NOVEMBER 1971

Each day, the previous day's forecasts for each of the three periods "today" (0800-1959 PST), "tonight" (2000-0759 PST), and "tomorrow" (0800-1959 PST) is verified and the present or preceding month's overall verification scores are indicated on the forecast sheet of the present morning (table D-2). At the end of each month, a memo is prepared from the Weather Center Officer to All Hands listing the verification scores of individual forecasters. In this way, an incentive is given to all forecasters, particularly those at the bottom of the list, to improve their forecasting abilities.

Table D-2. Daily Forecast Sheet Showing Final Verification Scores of Previous Month

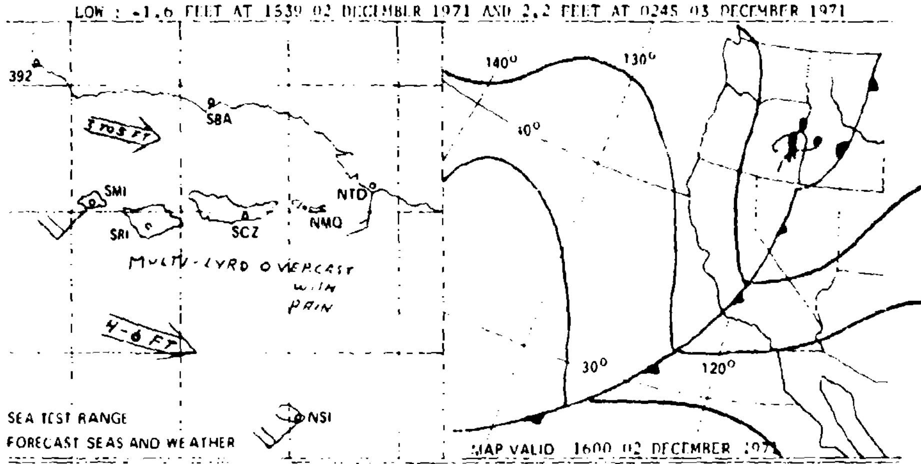
PMR AREA FORECAST
11ND-PMR-3145 1 (REV. 3-71)

All times local THURSDAY
For official use only. 02 DECEMBER 1971

FREEZING LEVEL 9,200 FEET

SUNSET TONIGHT 1647 | SUNRISE TOMORROW 0645

TIDES
HIGH: 3.8 FEET AT 2208 02 DECEMBER 1971 AND 6.9 FEET AT 0856 03 DECEMBER 1971
LOW : -1.6 FEET AT 1539 02 DECEMBER 1971 AND 2.2 FEET AT 0245 03 DECEMBER 1971

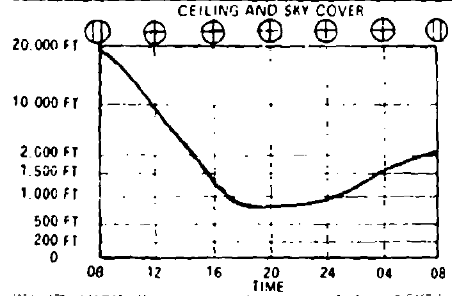


SEA TEST RANGE
FORECAST SEAS AND WEATHER

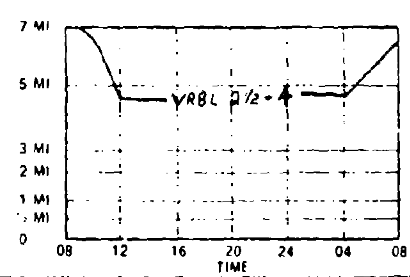
MAP VALID 1600 02 DECEMBER 1971

POINT MUGU FORECAST FOR PERIOD 0800 TODAY TO 0800 TOMORROW

CEILING AND SKY COVER



VISIBILITY



WEATHER

INCREASING MULTI-LAYERED OVERCAST WITH RAIN COMMENCING NEAR NOON CONTINUING UNTIL FRIDAY MORNING. RAIN MODERATE TO HEAVY TONIGHT.

SURFACE WINDS

NORTHEAST 3 TO 5 KNOTS THIS MORNING BECOMING SOUTHERLY 18 TO 22 KNOTS UNTIL NEAR MIDNIGHT THEN BECOMING SOUTHWESTERLY 10 TO 15 KNOTS.

MAXIMUM TEMPERATURE TODAY 55 | MINIMUM TEMPERATURE TONIGHT 48 | MAXIMUM TEMPERATURE TOMORROW 57

FORECAST FOR
FRIDAY: PARTLY CLOUDY WITH RAIN SHOWERS IN THE AREA FOR THE ENTIRE DAY. VISIBILITY 4 TO 7 MILES VICINITY RAINSHOWERS

OUTLOOK FOR
SATURDAY: CLEARING WITH WEST NORTHWEST WIND.

SAN NICOLAS ISLAND FORECAST

OVERCAST WITH RAIN AFTER NOON. CEILING 1,000 TO 2,000 FEET. VISIBILITY DECREASING THIS MORNING TO 5 TO 7 MILES THEN 3 TO 5 MILES IN RAIN. WIND SOUTHERLY 20 TO 25 KNOTS UNTIL FRONTAL PASSAGE THEN SOUTHWESTERLY 10 TO 15 KNOTS.

REMARKS

FINAL NOVEMBER FORECAST VERIFICATION SCORES

"TODAY" 89.0% "TONIGHT" 79.[illegible] "TOMORROW" 74.3%

ISSUED
LTJG G. D. McKAIGE/AG2 SR

APPROVED
FOR R. C. SHIPMAN LCDR

APPENDIX E

CLOUD AND SKY CONDITIONS AT POINT MUGU DURING STRATUS, SANTA ANA, AND RAIN-PRODUCING WEATHER REGIMES

Figure E-1. Low Stratus With Good Visibility Beneath, Typical of Conditions Following Weak Frontal Passage in Spring. View is to east toward Laguna Peak and Mugu Rock. (Photo taken at 1307 PST, 17 March 1967, by Robert deViolini, Geophysics Division.)

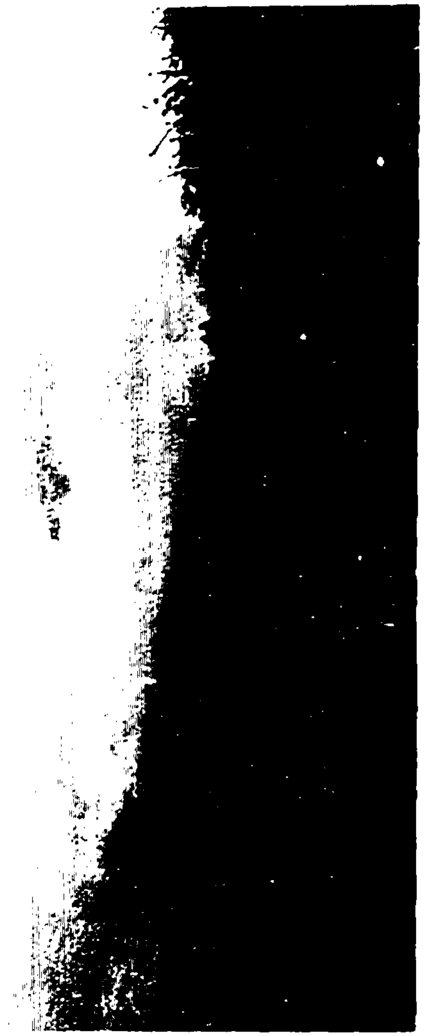


Figure E-2. Typical View of Stratus Filling the Valleys as Seen From Laguna Peak Looking East Into La Jolla Valley. (Photo taken at 0852 PST, 13 July 1967, by Robert deViolini, Geophysics Division.)

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Figure E-3. Typical Low Summertime Stratus With Top of Laguna Peak Visible in the Warm, Dry Air Above. (Photo taken at 1044 PST, 24 July 1967, by Robert deViolini, Geophysics Division.)

Figure E-4. Low Stratus and Fog Moving Over Point Mugu From Southeast While Santa Ana Northeast Winds Erode Stratus Seaward and Restrict Cloud to Shallow Layer. View is to east toward Laguna Peak. (Photo taken at 0800 PST, 16 March 1970, by PH1 J. J. Hollis, Photo Graphics Department.)

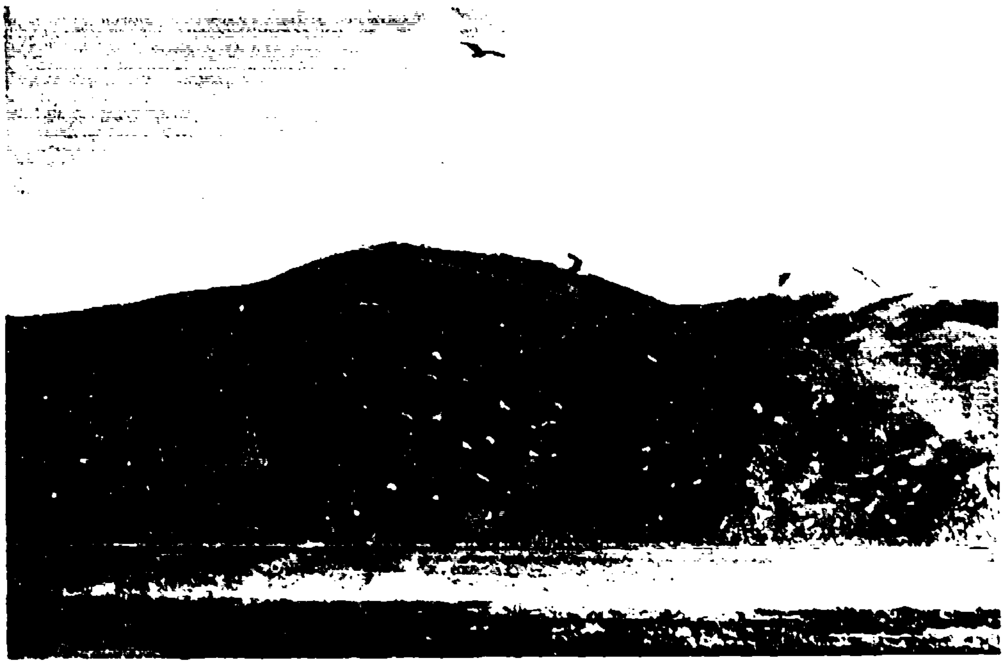

Figure E-5. Stratocumulus Over Laguna Peak With Good Visibility Beneath in Deepening Marine Layer Ahead of Weak Front and Trough Aloft. (Photo taken at 1241 PST, 23 March 1967, by Robert deViolini, Geophysics Division.)

Figure E-6. Stratocumulus, Heavy in Places, Following Showers. Trough and surface low is to southwest of Southern California. (Photo taken at 0830 PST, 10 November 1969, by William D. Gumbert, Airborne Photo.)

Figure E-7. Cap Cloud of Low Stratus Over Laguna Peak Immediately After Rain Shower. (Photo taken at 1155 PST, 21 December 1970, by Robert deViolini, Geophysics Division.)

Figure E-8. Towering Cumulus Typical of Very Unstable Air Mass With Trough Aloft. Cirrus [illegible] above cumulus. (Photo taken at 1420 PST, 7 November 1969, by William D. [illegible], Airborne Photo.)

Figure E-9. Shallow Cumulonimbus "Snowing Out." Formation is typical of unstable conditions with low freezing levels. (Photo taken at 1345 PST, 28 April 1970, by Robert deViolini, Geophysics Division.)

Figure E-10. Postfrontal Cumulonimbus and Heavy Shower Looking Offshore to South. (Photo taken at 0924 PST, 11 April 1967, by Robert deViolini, Geophysics Division.)

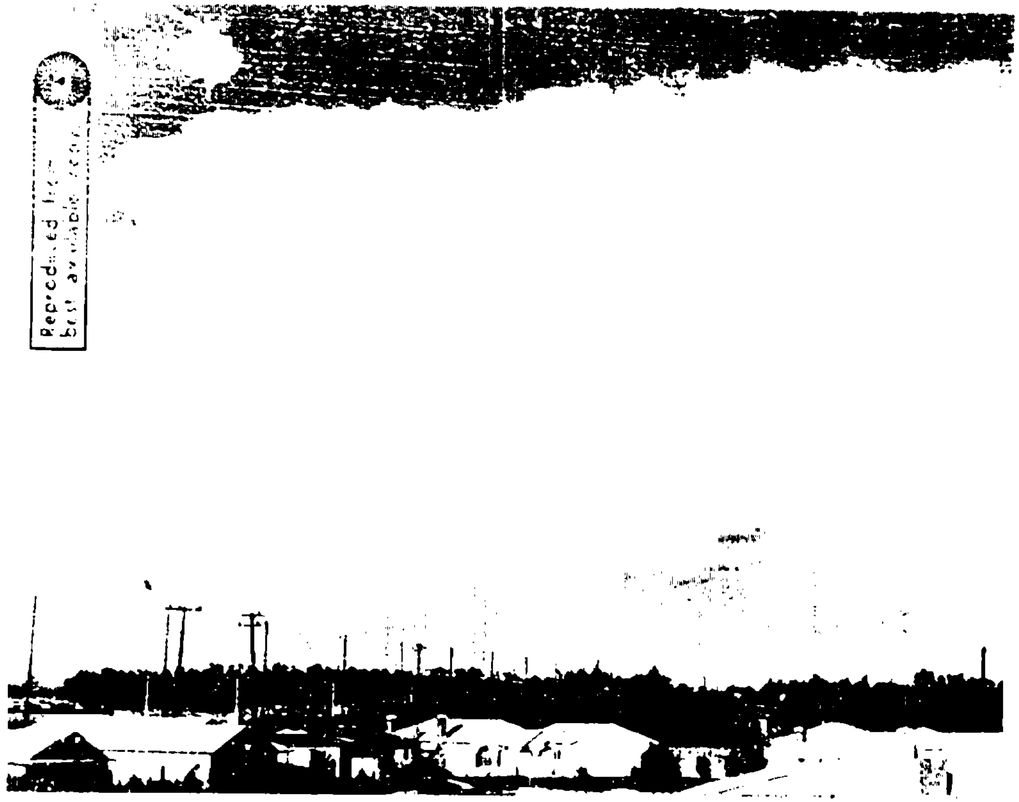

Figure E-11. Massive ... of Cumulonimbus to East of Point Mugu. (Photo taken at 1730 PST, 11 A... 67, by Robert deViolini, Geophysics Division.)

Figure E-12. Altocumulus Clouds. (Photo taken during winter, 1969-70, by William D. Gumbert, Airborne Photo.)

Figure E-13. Prefrontal Altocumulus, View to Southeast. (Photo taken at 0757 PST, 30 March 1957, by Robert [illegible], Geophysics Division

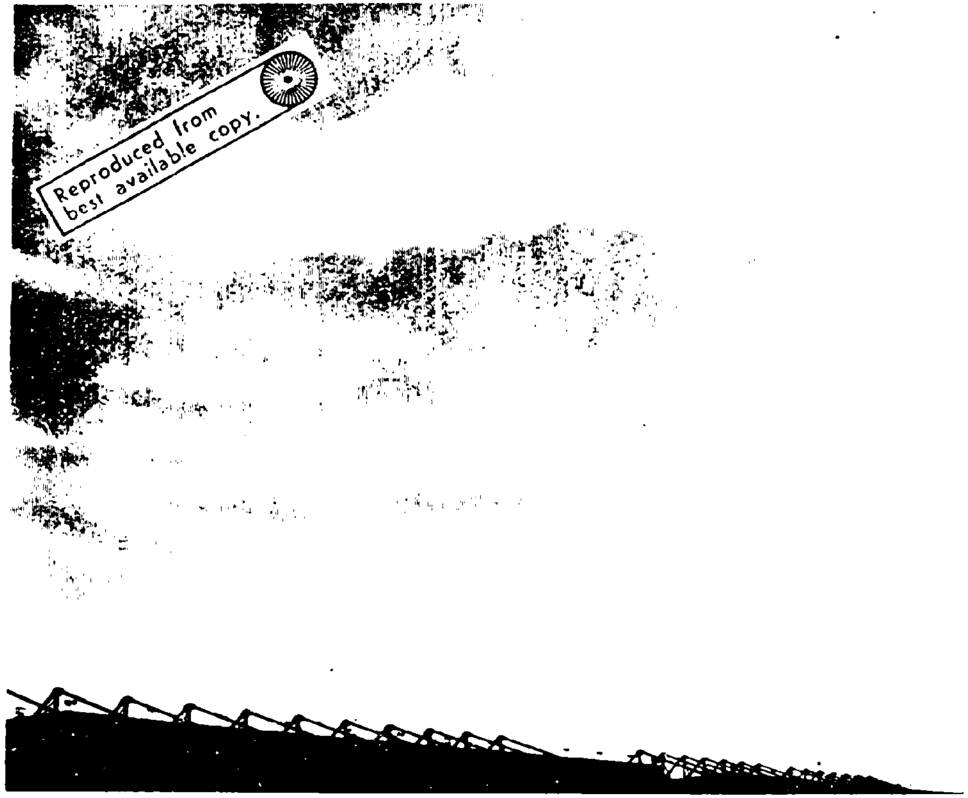

Figure E-14. Cirrus Clouds. (Photo taken during winter, 1969-70, by William D. Gumbert, Airborne Photo.)

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